Dependence of Temporal Frequency and Chromaticity on the Visibility of the Phantom Array Effect

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LIGHTING ENGINEERING SOCIETY OF SLOVENIA

ABSTRACT BOOKLET

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PROGRAMME

INVITED PRESENTATIONS

IP01

THE FUTURE OF INDOOR LIGHTING STANDARDS (AND HOW TO GET THERE)

Boyce P.R.[1] and Cuttle, C.[2]
[1] Independent Higher Education Professional, Canterbury, UNITED KINGDOM, [2] Lighting Consultant, Wellington, NEW ZEALAND
peter.robert.boyce@gmail.com

Abstract

Over the last two decades, lighting practice has changed dramatically. LEDs have become the dominant light source. Lighting controls have become easier to apply and more sophisticated. Knowledge of the non-visual effects of exposure to light has exploded. New metrics for describing colour perception have been developed. In this changing world one aspect of lighting practice has remained largely unchanged – indoor lighting standards.

Indoor lighting standards were first introduced in the first half of the 20th century as a means to ensure enough light was provided for the efficient performance of visual tasks in workplaces. Their scope soon expanded to cover a broad range of lighting applications, and other aspects of visual response to lighting such as discomfort, and thus became a means to eliminate bad lighting. In this they have been successful but today they can be a restriction on the freedom of lighting practitioners to produce good lighting. This is partly because standards have been issued for applications without critical visual tasks. Attempts have been made to ameliorate the fixation on the task by adding illuminance recommendations for walls and ceiling to give some emphasis to the lighting of the space. This is a move in the right direction but it leaves another problem unresolved. This is the design method usually used to ensure compliance with lighting standards, the lumen method. This assumes a regular array of luminaires and puts technology before perception. Essentially, the lumen method asks the practitioner to choose the technology first and then determines what illuminance will be achieved. Fortunately, there is now an alternative, the lighting design objectives procedure.

This differs from conventional lighting practice in that:

- At the outset, the practitioner identifies the lighting needs and opportunities presented by the application to form a list of lighting design objectives to be achieved.
- The criterion for maintained illuminance is spatial brightness, which is related to ambient illuminance. A spatial brightness lighting design objective is specified by a mean room surface exitance value.
- Wherever practical, other objectives are specified in terms of other lighting metrics.
- Lighting design objectives that involve illumination diversity, which may include a creation of visual emphasis or ensuring efficient flux utilance, are achieved by selecting target surfaces to receive direct flux and specifying values of target/ambient illuminance ratio.
- These specified values are related to the photometric properties of the space to determine an optimal direct flux distribution to achieve those lighting design objectives that relate to ambient illuminance or illuminance distribution.
- The selection of luminaires and the planning of the layout and controls are then directed to providing the required direct flux distribution, as well as achieving any of the practitioner's other chosen objectives.

In this way, the lighting design objectives procedure provides the practitioner with options that range from ensuring compliance with lighting standards, to designing unique solutions which exploit the needs and opportunities presented by the space, its contents, and the activities it

houses. Its general adoption would provide a shared basis for architects, interior designers, and building services engineers to describe, specify, and verify lighting design objectives for specific applications.

Why should any of this be of interest to the CIE? The answer to this question depends on the aspirations of the CIE. If its aspirations are limited to eliminating bad lighting, then the lighting design objectives procedure will be of little interest. However, if the CIE aspires to promote good lighting then the lighting design objective procedure offers a route to achieve this aim but not without a major change to indoor lighting standards. For a start, indoor lighting standards would need to be based on spatial brightness due to ambient illuminance, expressed as mean room surface exitance, rather than task illuminance in lux. Then, illumination diversity would need to be expressed as target / ambient illuminance ratio. There would also need to be major changes in the facilities available to lighting practitioners. Design software would need to be substantially revised. Full-field measurement devices would have to become commercially available to allow compliance with revised standards to be checked. Lighting equipment manufacturers would need to provide appropriate technical support.

To justify such an upheaval in general lighting practice, some research will be needed. The CIE itself does not undertake research but it knows people who can. Among the questions that would need to be addressed are:

- Is mean room surface exitance a stable metric for ambient illuminance in spaces that vary in size, shape and surface reflectances, with and without daylighting?
- How does light received directly at the eye from luminaires influence spatial brightness?
- How will the colour properties of light sources be expressed in indoor lighting standards?
- Is there a case for using ambient illuminance as a means for assessing the impact of light exposure on the human circadian system?
- Should indoor lighting standards be separated into a base case, legally applicable to all installations to ensure safety and consequential aspects such a limits on lighting energy consumption, and advisory guidance for specific applications?

Such a change in the basis of indoor lighting standards is not to be undertaken without careful thought but the question certainly deserves the attention of the CIE.

IP02

Has not been submitted yet

IP03

SEEING AND FEELING CHANGES IN DAYLIGHT OVER TIME

Hurlbert, A.[1]
[1] Newcastle University, Newcastle upon Tyne, UNITED KINGDOM
anya.hurlbert@newcastle.ac.uk

Abstract

We see colour because light interacts with particles and surfaces and then with the sensors in our eyes. But the concept of colour arises from attributing colour to objects as an intrinsic property, and this operation requires disentangling changes in illumination over time and space from changes in object properties – the perceptual phenomenon of colour constancy. To what extent is colour constancy constrained by the properties of natural illumination, under which it evolved? Here I will describe physical measurements of the spatial and temporal characteristics of natural daylight, and psychophysical measurements of human visual discrimination of temporal changes in daylight metamers. The dynamics of daylight exhibit a characteristic tripartite pattern: for chromaticity, the periods of fastest change occur in early morning and late evening at the lowest irradiances, with an interim period of relative stability. Illuminance changes are generally smooth and fastest at the day's extremities, except when disrupted by weather. These changes in natural illumination are generally too slow to be directly detected. On the other hand, people are sensitive to the illumination "atmosphere", exhibiting strong preferences and memory for particular illumination chromaticities in behavioural tests, and effectively reading the intended time of day from chromaticity-luminance correlations in landscape paintings. Scene stability – a measure of colour constancy – is strongest for temporal changes in illumination chromaticity towards neutral. One speculation is that visual mechanisms dampen sensitivity to the largest natural changes in illumination chromaticity in order to maintain perceptual stability of object color. Conversely, nonvisual mechanisms appear tuned to chromaticity changes at dawn and dusk, and hence are critical for syncing the circadian clock with environmental conditions. The latter might also feed long-term memory of illumination conditions as well as subjective experiences of illumination atmosphere.

ORAL PRESENTATIONS

Session PA1-1
D2 - Spectroradiometry and photometry

Monday, September 18, 10:50–12:10

OP40

RECONSTRUCTION OF CAMERA SPECTRAL RESPONSIVITY USING MULTIPLE NARROW-BAND LED RADIANCE SOURCES

Bouroussis, C.A., Blattner, P.
Federal Institute of Metrology, METAS, Bern, SWITZERLAND
constantinos.bouroussis@metas.ch

Abstract

1. Motivation, specific objective

Imaging sensors are widely used in photometry and lighting engineering for lighting measurements, facilities inspections, glare assessment and other. In many cases, the equipment in use is not a dedicated ILMD (especially when colour information is needed) but a generic imaging sensor in the form of a commercial digital camera, an industrial vision sensor and other. To exploit these devices as photometric instruments, the users either use the spectral responsivity given by the manufacturer or they try to characterize the device themselves. In this case, the most common facility is a monochromator setup with a broadband light source. This approach leads to accurate results. However, it demands complicated and expensive equipment and a time-consuming characterization process. In addition, in most cases, the irradiance levels on the sensor surface are so low that makes this process not adequate for specific spectral ranges.

The majority of the stakeholders which deal with this type of devices have no access to such an expensive characterization setup. Therefore, they use on most cases the theoretical spectral responsivity of the cameras and try to validate them (where possible) only in few key wavelengths using some reference sources.

The motivation of this study was to investigate the possibility to reconstruct the spectral responsivity of a camera using a fast, economical and reliable method. The target was to retrieve the camera responsivity using a set of narrowband LEDs. In this respect, the method should be optimized for monochrome and RGB sensors with a potential extension to cameras equipped with standardize photopic filter

2. Methods

This study is divided in three parts. The first part includes the theoretical development of the reconstruction algorithm using a hypothetical camera responsivity and a set of theoretical narrow-band radiance sources. The theoretical radiance sources were parametrically generated to have specific peek wavelength, FWHM and relative radiance. Several sets were created with different combinations of theoretical sources. For the hypothetical spectral responsivity of the imaging sensors, some typical monochrome and RGB sensors responsivity curves were selected. The reconstruction of the spectral responsivity was based on an optimization algorithm which incorporated curve fitting using Legendre polynomials and local splines. The target was to find the minimum number of radiance sources and their distribution along the spectrum in combination with the minimum number of Legendre or splines polynomials that can adequately reconstruct the hypothetical spectral responsivity of the camera.

The second part comprises the application of the algorithm on real measurement data using imaging sensors as test devices and a tuneable LED light source as the input source. The tuneable source offers 32 narrow-band LED source with around 15nm spacing and around 20nm FWHM and 3 wide-band LED sources at various radiance levels. The LED sources are spread from 360 to 1100 nm. The tested cameras were two industrial vision cameras, one equipped with RGB matrix filtered sensor and the other with a filter-less (monochrome) one. The reconstruction algorithm was tested using different combinations of LED sources, different number of polynomials and in various spectral ranges. In this process, the real responsivity of the camera was considered as unknown. In the case of the RGB camera, the

RGB channels were considered both as corelated and uncorrelated to investigate the efficiency and the limitations of the algorithm.

In the third part, the curve reconstruction results were validated as well as the sensitivity of the algorithm on various sources of uncertainty was calculated. For this purpose, the spectral responsivity of the cameras was measured using a reference source (double monochromator) and the results were compared to the ones of the reconstruction algorithm. In parallel, the uncertainty in the calculation of photometric quantities using the reconstructed responsivity versus the real one was estimated.

3. Results

The proposed method for the reconstruction of the camera responsivity resulted to sufficient results, especially for the theoretical calculations where the reconstructed curve was almost identical to the hypothetical one. In the case of the real measurement data, the results can be also considered as adequate when the uncertainty of the input data (spectral power of sources and relative irradiance on the sensors) are relatively low. It was also observed, that in spectral ranges beyond the range of sensitivity of the camera, the reconstruction results suffer from noticeable errors.

4. Conclusions

The presented algorithm offers a convenient method for the reconstruction of the spectral responsivity of a camera without the need of a complex characterization setup like a monochromator. The proposed method can be used by an extensive group of stake holders using relatively inexpensive equipment and the results can be used in a variety of lighting engineering and photometry applications up to the point where the spectral mismatch between the real and the calculated responsivity increases the measurement uncertainty beyond the desired thresholds.

OP61

SENSITIVITY EVALUATION OF MEASUREMENT UNCERTAINTY CONTRIBUTIONS OF SPECTRAL DATA FOR CALCULATED INTEGRAL QUANTITIES

Krüger, U.[1], Ferrero, A.[2], Thorseth, A.[3], Pellegrino, O.[4], Dubard, J.[5], Ikonen, E.[6], Sperling, A.[7]
[1] TechnoTeam Bildverarbeitung GmbH, Ilmenau, GERMANY, [2] Instituto de Óptica, Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, [3] Technical University of Denmark, Roskilde, DENMARK, [4] Departamento de Metrologia, Instituto Português da Qualidade, Caparica, PORTUGAL, [5] Laboratoire National de Métrologie et d'Essais, Paris, FRANCE, [6] Metrology Research Institute, Aalto University, Espoo, FINLAND, [7] Physikalisch-Technische Bundesanstalt, National Metrology Institute of Germany, Braunschweig, GERMANY
udo.krueger@technoteam.de

Abstract

1. Motivation, specific objective

The integration of spectral data (spectral responsivities of photometers or spectral distributions of the optical radiation of light sources) to calculate quantities like luminous responsivity, luminance, tristimulus values, or spectral mismatch correction factor is straightforward at first sight. However, the estimation of the measurement uncertainty of these integrated quantities is a challenging and complex process. Some uncertainty contributions from the spectral data "cancel out" due to normalization effects, while others "average out" due to the integration operation over the wavelength range. The correlation between measurements at different wavelengths can significantly contribute to the combined uncertainty of the integrated quantities.

This work aims to establish a basic approach based on Monte Carlo Simulation (MCS) to estimate the sensitivity coefficients for calculating the measurement uncertainty of integral quantities from spectral measurements.

2. Methods

For the basic approach of the simulation, values at the different wavelengths and values from the amplitude scales are evaluated separately. The proposed basic approach does not describe a measurement technique but the impact of correlated spectral measurements in the calculation of spectrally integrated quantities, and therefore does not include the physical background of a particular measurement setup or device under test (DUT). The model makes it possible to understand the main contributions of the spectral measurements to uncertainty and consider them for specific cases.

On the other hand, the evaluation process allows possible correlations between the output quantities to be identified by this basic approach. For instance, the overlap of the CIE colour-matching functions in the wavelength range generates correlations between the tristimulus values.

According to the methodology to be presented, the uncertainty contributions of the spectral data are represented as values with specific distribution probabilities, divided into additive and multiplicative components, and for both categories in uncorrelated, fully correlated and partially correlated values. The partially correlated values are modelled by orthogonal base functions or by applying known covariance matrices from other measurements.

The subsequent application of these types of contribution (and all together at the end) estimates the possible sensitivity coefficients (the variation of the output quantity with respect to the variation of the input quantity). This kind of sensitivity analysis is called one factor at a time.

As an example, a blackbody spectral distribution is used as input quantity to make the simulation as simple as possible. Based on the theoretical blackbody radiator, the spectral

and wavelength values are modified during the MCS as described above. With the modified spectral distributions, one can calculate output integral quantities (e.g. luminance, tristimulus values, CCT, Duv or the spectral mismatch correction factor) and study their behaviour during the simulation. These data estimate the probability distribution functions and statistical parameters for all output quantities, including mean and standard deviation. As a first step, their relations are described with linear correlation coefficients and correlation plots.

3. Results

The simulations show the expected behaviour, meaning that uncorrelated and fully correlated contributions do not significantly affect tristimulus values and derived quantities. The exception is the contribution from the additive, fully correlated errors in the values of the wavelengths (e.g. caused by the homing/initializing procedure of a monochromator or by the wavelength adjustment of an array spectroradiometer with a few spectral lines only), which makes significant contributions to nearly all investigated output quantities.

However, it was shown by modelling with orthogonal base functions that partial correlations contribute significantly to the measurement uncertainty, especially if the number of base functions is small. This is a possible contribution to the measurement uncertainty that needs to be considered for physical models.

4. Conclusions

The suggested basic modelling approach is an easy way to understand the origin of possible significant contributions to measurement uncertainty, caused by correlation in the spectral data used as input quantities or by the evaluation process itself.

Besides the fully correlated noise on the wavelength scale, the partially correlated contributions, which can be described with orthogonal base functions, are significant and need to be studied in further investigations.

OP77

SPECTRAL DEPENDENT NON-LINEARITY OF CHARGE ACCUMULATING PIXEL MATRIX SENSORS

Schrader, C.[1], Ledig, J.[1]
[1] Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
christian.schrader@ptb.de

Abstract

1. Motivation, specific objective

Camera systems based on charge accumulating pixel sensors (e. g. CCD, CMOS) are widely used to carry out quantitative measurements of light distributions, especially when used in imaging luminance measurement devices (ILMDs). To increase the accuracy of the measurements these devices need to be characterized in a way that significant systematic effects can be corrected. One element of this characterization is the non-linearity of the system. A common way to determine this non-linearity is by variation of integration time. For an ideal system and after the subtraction of internal offsets, the output signal of the sensor (count signal) should increase linear with the integration time. With other words: the count rate should be constant.

The resulting characteristic is often a curved line from low to high count values and scaled by normalization to a region around 1. One class of non-linearity characteristics attracted our special interest because it was not what we expected: The normalized non-linearity curve started at low counts with positive values about +3%...+2% and then decreased *linearly* down to about -2%...-3% at high count values. The origin of non-linearity is usually considered to originate from random imperfections of the pixels and the components that carry out the signal processing, namely the analogue front-end including the AD-converter. This seem to be contradicting to the nearly linear decrease indicating a systematic effect. The fact that this behaviour was seen on different devices (ILMD and industrial cameras) lead to the assumption, that there must be another mechanism that causes this behaviour. This work will discuss the search for the underlaying mechanism and its correction by post processing of the measurement signal.

2. Methods

The part in the measurement process where this non-linearity is introduced can be the charge generation and collection, their accumulation, possible recombination of charges, the readout of accumulated charges and different parts of the signal processing (amplification, correlated double sampling, optical black clamping, analogue offset, AD-conversion, …). To find out which part causes this linear slope of the non-linearity, measurements with various parameter sets were carried out. The integration time was varied from very short to long by using neutral density filters to change luminance levels. Some cameras allowed to vary the internal clock frequency. This changes the readout timing and thereby the operating conditions of the analogue front end. The spectral distribution of the source was changed from illuminant A to single-color LED-based luminance standards.

3. Results

With these variations it could be shown that the underlaying mechanism of the linear slope of the non-linearity is linked to the relative spectral distribution of the source. The luminance standard commonly used by us for the non-linearity characterization is one based on an incandescent lamp (illuminant A). The corresponding non-linearity curve showed a similar form like the one with red light. With green light the linear slope was much lower and with blue light the linear slope was zero. Because of these findings, the spectral dependency was characterized in more detail using monochromatic irradiation and scanning a spectral range from 350 nm to 1000 nm. This showed that the increase of the linear slope started between

500 nm and 550 nm. For monochromatic irradiation above 800 nm the linear slope kept constant.

This behaviour can be explained by the combination of two effects. The absorption coefficient of the light and therefore the charge generation profile inside the photodiode depends strongly on its wavelength. While the charges are accumulated inside the pixel, the depletion zone of the photodiode is reduced. For long wavelengths the charge generation profile exceeds the depletion zone. As a results of this effect, which severity depends on the internal structure and doping profile of the pixel, the charge collection rate changes during the integration time. What renders as the signal responsivity is the effective, averaged collection rate (photocurrent accumulated over the integration time).

4. Conclusions

That the observed overall non-linearity consists of two components, one of the signal-processing chain and one spectral dependent, allows to compensate them separately if the evaluated regions in the image result from different spectral distributions. The non-linearity determined using blue light (with low penetration depth) can be assigned to the analogue signal-processing chain. The remaining spectral non-linearity can be modelled as a wavelength dependent tilt (slope of the linear decrease inside the non-linearity). For broader spectral distributions an “effective” wavelength needs to be estimated by the centroid wavelength. In case that the spectral distribution of the sources to be measured is not known, an effective approach to estimate the slope of the spectral component for each pixel individually is to utilize a sequence of a few images of different integration time to determine the effective slope of the linear decrease of the non-linearity from the count rates.

OP35

METROLOGICAL IMPACT OF INTRODUCING CONE FUNDAMENTAL-BASED PHOTOMETRY AS THE BASIS TO DERIVE PHOTOMETRIC UNITS

Shitomi, H.[1]
[1] National Metrology Institute of Japan (NMIJ, AIST), Tsukuba, JAPAN
h-shitomi@aist.go.jp

Abstract

1. Introduction

Practical realization of photometric units has been implemented by referring the CIE system on physical photometry. To derive photometric quantities, consideration on the standard spectral luminous efficiency function (for photopic vision) $V(\lambda)$ is indispensable.

While $V(\lambda)$ has been internationally accepted as the basis of the current photometric system for long time, some critical technical issues have been raised. For example, it has been often criticised that the spectral response property of $V(\lambda)$ in shorter wavelength region may be considerably underestimated and 2° field of view may not represent the normal viewing condition.

Precise spectral modelling of human visual response by physiological and biological analysis of the eye has been studied worldwide, which was summarised by CIE as the CIE2006 cone fundamentals. CIE published two technical reports (CIE170-1 and CIE170-2) on this topic. They enable us to derive the updated colour matching functions and the spectral luminous efficiency function for the normal observer, depending on visual angle and the age.

In the 25th plenary meeting of Consultative Committee for Photometry and Radiometry (CCPR) in May 2022, it was proposed that the cone fundamental-based spectral luminous efficiency function $V_F(\lambda)$ should be considered as a possible replacement of the basic function to derive photometric quantities. It was emphasised that introducing $V_F(\lambda)$ instead of current $V(\lambda)$ would contribute to resolve the technical problems $V(\lambda)$ has had and to realise more reliable evaluation of light and human perception in the SI.

This concept directly connects to the change of definition of photometric units, which gives big impact, either positive or negative, to various stakeholders. So, impact assessment with various viewpoints is necessary to identify key issues and to determine if the replacement is worthy or not. This paper discusses the potential impact of the replacement of $V(\lambda)$ to $V_F(\lambda)$ in terms of metrological and instrumental aspects.

2. Methods

First, the potential difference between $V(\lambda)$-weighted and $V_F(\lambda)$-weighted photometric values was analysed. What was focused on this analysis is the range of change depending on the spectral power distribution (SPD) of a targeted source. For coloured sources, simulated sources with various peak wavelength (from 450 nm to 750 nm) and bandwidth (from 20 nm to 100 nm) were analysed. For white sources, simulated source based on the data set CIE prepared such as CIE illuminants and daylight were taken for the calculation. In addition, around 100 SPD data of real white sources were prepared and potential variation of the difference and their dependence on SPDs were analysed. Calculation of the photometric value was made according to ISO/CIE 23539.

Second, the quality index f_1' was chosen as a representative figure to express the performance of photometric instruments. 8 commercial illuminance meters and 2 $V(\lambda)$-corrected photodetectors were prepared. Their relative spectral responsivities were calibrated against the spectral responsivity standard to obtain their f_1'values. A new quality index $f_{1,F}'$ was introduced by applying $V_F(\lambda)$ as reference photopic function instead of $V(\lambda)$ and compared with original f_1' for each instrument.

3. Results

For coloured sources with spectral bandwidth of 20 nm, which represent typical coloured LEDs, the maximum difference of the photometric value at each peak wavelength ranged -10,8 % to 64,8 %. The shorter the peak wavelength was, the more difference was observed. Even though increasing the spectral bandwidth resulted to decrease the dependence of peak wavelength, there remained the difference from 3,2 % to 12,2 % for the sources with the spectral bandwidth of 100 nm. In the case of white sources, the average difference of 5,3 % with the standard deviation of around 0,4 % was observed. When all the types of white sources were compared, no explicit correlation between the change of the photometric values of the sources and their CCTs was observed.

If the difference between $V(\lambda)$-weighted and $V_F(\lambda)$-weighted photometric values is nearly constant for all the sources, it would be possible to introduce a new technical constant $K_{cd,F}$ for luminous efficacy of radiation at 540 THz, instead of K_{cd} = 683 lm W^{-1} in the current SI, to compensate the change. However, it was revealed that the change of the photometric function inherently had non-negligible dependence on the SPD. The potential variation for white sources is comparable to the expected uncertainty of photometric calibration in National Metrology Institutes (NMIs), and around the half to the quarter of that in industry.

f_1' values of Illuminance meters and $V(\lambda)$-corrected photodetectors used in this study ranged 2,5 % to 13,8 % for the CIE illuminant A. Observed difference between f_1' and $f_{1,F}$' values were from -3,1 % to 4,0 %, which is beyond the expected uncertainty of f_1' determination. 8 instruments out of 10 resulted to have poor photopic approximation when $V(\lambda)$ was replaced by $V_F(\lambda)$, whereas two of them showed better approximation to $V_F(\lambda)$ rather than $V(\lambda)$. That would attribute to difficulty in designing a photometer with good approximation to $V(\lambda)$ in blue region where big difference between $V_F(\lambda)$ and $V(\lambda)$ exists.

The CIE classification system for photometers specifies four instrument classes from CIE4* to CIE1*, each of which has the limit f_1' value of 1,5 %, 3.0 %, 6.0 % and 9.0 %. The potential change of the value when f_1' is replaced with $f_{1,F}$' would lead to the failure to keep the instrument into a specific class. That is fatal when the classification is connected to pass/fail criterion such as legal metrology.

4. Conclusions

Impact assessment on the replacement of photometric function from $V(\lambda)$ to $V_F(\lambda)$ was made by analysing the potential change of photometric values as well as the instrument quality index. $V_F(\lambda)$-weighted quantities resulted in the change of photometric values depending on the SPD of targeted source. Even for white sources, there are SPD-dependent variations comparable to the uncertainty of photometric calibration. The difference between f_1' and $f_{1,F}$' affects product specifications in terms of the instrument classification. It is concluded that the potential changes observed in this study are not negligible in many cases.

Session PA1-2
D3 - Office lighting

Monday, September 18, 10:50–12:10

OP57

EMOTIONS ASSOCIATED WITH AN OFFICE ILLUMINATION AND A PROCESS TO IMPROVE THEM

Karlsson, B.[1], Brauer, H. B.[1,2], Hedekvist, P.O.[1], **Enger, J.[3]**, Wallin, K.[4], Ryberg, K.[5], Mayerboeck, V.[6], Laike, T.[7]

[1] RISE Research Institutes of Sweden, Göteborg, SWEDEN, [2] University West, Trollhättan, SWEDEN, [3] Konstfack, Stockholm, SWEDEN, [4] Fagerhult, Stockholm, SWEDEN, [5] Monocrom, Stockholm, SWEDEN, [6] Allesoderlicht, Vienna, AUSTRIA, [7] Lund University, Lund, SWEDEN

bodil.karlsson@ri.se

Abstract

1. Motivation, specific objective

Emotions are important for well-being, co-operation and work performance in an office environment. Several researchers have pointed out connections between illumination and emotion. Terms like *human centric lighting and integrative lighting* have become increasingly popular both in science and marketing and put focus on the importance to research the complex interaction between human and light surroundings. Much is known about how e.g., temporal pattern, light spectrum, light level and spatial pattern reaches the human brain through photoreceptors in the eye and interact with brain and bodily functions such as the circadian system

However even if much is known the knowledge about emotion in relation to light is far from complete and more research is needed to understand the complex interplay between light and emotion. For example, even more complex emotional judgments seem to interplay with light, e.g., there is research suggesting that employees rated colleagues as more competent in light environments that they preferred and faces less fearful in warmer light.

A practical problem that may arise in an office environment is that people complain on the light for loose reasons e.g., that it does not feel good. Given the assumption that emotional associations to light is an important aspect in offices, how can such emotional associations be understood, measured and improved? In a real-life scenario, if people are dissatisfied emotionally with a light environment, how should one understand, measure and eliminate such dissatisfaction? Furthermore, given that there is an increasing focus on energy efficiency performance in buildings, there is a need to make sure that the light environment is aligned to the needs of the users, in order for the performance of the building as a whole to be successful and sustainable over time.

Drawing on knowledge within psychology and perception research we designed a study to investigate how to improve emotional associations to light. The objective with this study was 1) to measure emotional associations to illumination in an open plan office in Sweden where some users experience problems e.g., headache and negative emotions 2) to develop a method for measuring feelings associated with light with the purpose to improve the emotional associations to light in a real life context, e.g., when redesigning an office space.

2. Methods

The study was conducted in an open-plan office in Sweden. The office had three different zones (active zone, silent zone and intermediate zone). There were two kinds of fixtures distributed evenly in the office space; round directed downlights and square pendulum fixtures with directed light downward. There was no indirect light in the open areas.

This study used a form of convergent mixed-method design meaning an approach where quantitative methods (survey and technical measurements) and qualitative methods (semi-structured interviews) were combined and conducted in parallel.

About 50 people answered the survey and five interviews were made. Interviews were analyzed with thematic analysis and survey data was analysed statistically. To find connections between expressed subjective experiences and quantifiable objective properties, physical measurements was performed to specify the areas most highlighted by the interviews. Measurements of illuminance, spectral content and temporal modulation in different areas of the office were performed.

3. Results

By using our mixed-method design, improvement possibilities were found. The office illumination was on average perceived to be rather unemotional, uniform and flat, and not so energetic. Correlated Colour Temperature (CCT) and Colour Rendering Index (CRI) was calculated from the spectra. There were no detectable flicker (SVM < 0,025) and all light sources are LED based with CCT = 3000 K and Ra > 83. The interviews suggested that some emotions in relation to the illumination were complex and intertwined with the work context as a whole and the individual’s associations.

4. Conclusions

We suggest that emotions in relation to light can be bottom-up driven (light stimuli induce emotions), top-down driven (user emotions are projected on the light solution) or context driven (e.g., interior design, type of task, and other people affect emotions associated with light). Furthermore, emotions in relation to light can be personal or shared in a group. In an open office setting, individualization is often possible for desks and chairs in order to provide a comfortable individual space, but light conditions are often shared. We suggest that, as much as possible, it is desirable be to meet individual needs also regarding emotions in relation to light and innovative solutions for individualisation of light in open-plan offices are called for. Drawing on emotions and perception research in psychology and neuroscience we suggest a holistic step-by-step process to improve emotional associations to light, starting with measurement and understanding of emotions in relation to light. We suggest in line with other researchers that improving emotional associations to light can be done by changing the illumination, but also in other ways (e.g., by changing the interior design). Our results also suggest further light and illumination research to consider the possible application of theories suggesting top-down processes in visual perception, and emotions as constructed mental events.

OP11

EFFECTS OF DYNAMIC LIGHT PATTERNS WITH NATURAL AND NON-NATURAL TEMPORAL COMPOSITION ON REPORTED STRESS RECOVERY, FASCINATION, AND ASSOCIATION WITH NATURE

Karaman-Madan, O., Linders, I., Chamilothori, K., de Kort, Y.
[1] Human-Technology Interaction group, Eindhoven University of Technology, Eindhoven, the Netherlands
o.karaman.madan@tue.nl

Abstract

1. Motivation, specific objective

The temporal variability of daylight is consistently mentioned as one of its unique characteristics that could explain our strong preference towards daylight compared to electric light sources. Nevertheless, little is known about people's responses to short-term temporal changes in daylight conditions, and particularly to those that are momentary and unpredictable, such as a breeze creating dynamic dappled light patterns (i.e., sunlight filtered through a tree canopy). Results from a recent online study comparing subjective responses towards static and dynamic dappled light imagery showed that the dynamic dappled light was more preferred and rated as more fascinating and more strongly associated with nature compared to static dappled light. This association of a stimulus with nature appears to be central in our experience and to have beneficial effects: exposure to both nature and to elements that imitate nature (such as using natural imagery in projections or wallpapers) has been shown to be preferred and to help in recovery from and resilience towards stress and fatigue. As a result, there is a growing interest in translating natural elements to interventions that could induce these beneficial effects of nature indoors, but the role of lighting as such an intervention has been largely overlooked.

This study investigates the potential of dynamic lighting projections for stress recovery in a laboratory experiment simulating a single-person office. Building on the knowledge gap regarding the momentary temporal variability in daylight and the promising findings about dynamic dappled light, this study focuses on effects of natural light dynamics per se, i.e., of dynamic light patterns that follow the temporal composition of dappled light compared to a non-natural temporal composition, and that are otherwise void of naturalness cues, such as shape or colour.

2. Methods

A single factor between-subjects experimental design was used to investigate the effects of temporal composition of projected light patterns on reported recovery from stress and on the experience of projected light. The between-subjects factor was the projected light, with three levels: a dynamic condition with a temporal composition of light patterns derived from dynamic dappled light (natural movement), a dynamic condition with a non-natural temporal composition of light (non-natural movement), and a static condition using a single frame from the natural movement condition (control). The natural movement condition was created by deriving the position, size, and movement of sunlight patches using MATLAB from a video of dynamic dappled light. In each video frame, each sunlight patch was translated to a circle with the same area and positioned at the geometric centre of the corresponding sunlight patch, resulting in a five-minute video with black background and white circles that changed size and position according to the original dappled light video. The non-natural movement condition was created by manipulating the position and size of each circle to deviate from the movement of the corresponding sunlight patch. The position of each circle between two consecutive frames was randomized while maintaining the same Euclidian distance, and its size was ordered to change from small to large. The mean luminance was similar between the dynamic conditions, and the mean size, speed, and number of circles remained constant. The conditions were

projected to the office wall and were adjusted so that only the white circles (and not the background) were visible.

The Mannheim Multicomponent Stress Test (MMST) was employed to increase participants' stress levels during the experiment and allow the investigation of stress recovery effects. MMST includes a cognitive stressor (a modified computer version of the Paced Auditory Serial Addition Task (PASAT)), an emotional stressor (images from the International Affective Picture System inducing negative valence), a motivational stressor (expected loss of compensation based on PASAT performance), and an acoustic stressor (white noise gradually increasing from 60 to 78 decibel).

Experimental sessions lasted 30 minutes and 67 participants (29 males, 36 females, 2 non-binary; M_{age} = 24, SD_{age} = 6.13) took part. After baseline measurements and conducting the MMST for five minutes, participants were exposed to one of the conditions (block randomized) during a five-minute recovery period. In this paper we focus on subjective measures of stress, which were asked immediately before (pre-stressor) and immediately after (post-stressor) the stressor, as well as after the recovery period (post-recovery), and included the Tense Arousal factor from the Activation-Deactivation Adjective Check List and a Visual Analogue Scale (VAS). After the recovery period, participants were asked to evaluate the projected lighting, and in this paper we examine how fascinating, stressful, and associated with nature the lighting was perceived (rated from 0, not at all, to 10, very).

3. Results

Analyses were parametric or non-parametric following data normality. A Wilcoxon signed-ranks test between the pre- and post-stressor ratings showed that the stressor was effective for tense arousal and VAS. However, a one-way ANCOVA with post-stressor ratings as a covariate showed no influence of condition on post-recovery stress for either tense arousal or VAS. Contrary to our expectations, a Kruskal-Wallis analysis also showed no effect of condition on association with nature, indicating that the lighting condition that imitated dappled light movement was not perceived as more natural than the "non-natural movement" condition. On the other hand, a one-way ANOVA did show that condition significantly influenced fascination ratings, with post-hoc pairwise comparisons showing lower fascination for the static compared to both natural and non-natural movement conditions, and no differences between them. Moreover, Kruskal-Wallis analyses showed that the two dynamic lighting conditions were perceived as more stressful than the static condition, with no differences between the natural and non-natural movement conditions.

4. Conclusions

This study investigates –to our knowledge, for the first time— experience and stress recovery stress using light stimuli with natural and non-natural temporal compositions. Results show that both dynamic lighting conditions were perceived as more fascinating but also more stressful than the static condition, and that the natural temporal composition characteristics employed in this study were not sufficient to be recognized as being strongly associated with nature.

OP74

BIODYNAMIC LIGHTING IN PRACTICE: PILOT STUDY IN A GOVERNMENT OFFICE

Raue, A.K.[1], te Kulve, M.[1]
[1] BBA Binnenmilieu, Den Haag, THE NETHERLANDS
ar-bba@binnenmilieu.nl

Abstract

1. Motivation, specific objective

A pilot study with biodynamic lighting was conducted in a government office in daily practice. The aim of the study was to investigate the pros and cons of biodynamic lighting in terms of energy use, occupant wellbeing and practical issues, and assess its fitness for rollout over the full governmental building stock. The pilot was part of a program that assessed several innovative technologies in a comparable manner.

In this context, biodynamic lighting is defined as ambient workplace lighting that can be varied in intensity and colour temperature over time, intending to mimic the diurnal cycle of natural daylight and thus improve the occupants' sleep/wake cycle. The hypothesis was that biodynamic lighting can stimulate employees' alertness at work and improve sleep quality and recuperation after hours. This should result in more wellbeing and productivity at no significant energy increase.

2. Methods

Tunable white LED lighting with a Dali controlled clock program was installed on the 6th floor of a typical office building. A questionnaire was used to assess the occupant perception of the 6th floor lighting system in steady before and after the transition to LED lighting. Participants were employees of a governmental organisation located in the building and performed their usual work activities, mainly working on a computer and having meetings.

Then, an experiment including two dynamic lighting scenarios was run on the 6th floor, both interventions running for five weeks with a baseline of two weeks in between. The baseline conditions were 350 lux and 4000K, comparable to the light conditions on the other floors of the building. After the 2-weeks baseline period with steady state lighting, the first intervention took place in which the light intensity was varied over the office hours. It started at 350 horizontal lux in the morning, peaking at 1200 lux at noon and gradually dimming back to 350 lux over the afternoon. After complaints, the peaks were ultimately reduced to 800 lux.

After another steady state baseline period, the second intervention followed a similar dimming cycle and in addition changed in colour temperature from 3300K in the morning to 5000K at noon and back to 2800K in the late afternoon. The interventions were symmetrically planned around the equinox (21st December) to obtain a comparable bias by daylight hours. The experiments took place from November 2019 until February 2020.

Before, during and after the interventions, the occupants' response was assessed using online questionnaires, interviews and three validated productivity tests from the Cambridge Brain Sciences cognitive test battery: *Double Trouble*, *Rotations* and *Spatial Planning Task*. Meanwhile, energy consumption was monitored for each floor in the building.

3. Results

The within-subject evaluation of steady state lighting versus the dynamic lighting scenario's showed lower occupant satisfaction during the dynamic conditions. Especially the noticeable transitions in colour temperature and intensity, the perceived brightness of the lighting scene,

discomfort glare and lack of personal control were reported to cause discomfort. Self-reported productivity and wellbeing varied a little inter scenarios, however were too small or inconclusive for attributing them to the specific interventions. Due to the expected effect size, the sample size and unexpected influencing factors, it can *not* be concluded whether or not the biodynamic protocols resulted in non-visual effects.

The interventions had a significant effect on the energy consumption and increased along with an increasing light intensity.

4. Conclusions

Although the study is inconclusive about the non-visual effects of biodynamic lighting, some valuable lessons were learned for further pilot studies and, finally, successful implementation of biodynamic lighting. Especially non expected factors such as noticeable dimming steps, apparently lasting occupant aversion of the whole concept after a rather high-stimulus experiment start (the intensity peaks were decreased several times after occupant feedback) and fading participants interest can be managed in further studies and applications.

It was also concluded that in a field experiment, many factors outside working hours influence the outcome measures on productivity and wellbeing thereby requiring a large sample size to detect possible effects of the dynamic light scenario's.

Anyhow, it can be concluded that a 'bigger is better' approach, i.e. strongly increased light intensity and colour temperature, does not necessarily result in more happiness and wellbeing. This is good to know, as the applied protocols followed common guidelines for *Human Centric Lighting* and the dynamic lighting system was comparable to the systems that are marketed by several manufacturers.

OP81

OFFICE LIGHTING FOR LIGHT-SENSITIVE INDIVIDUALS: A PILOT TEST

Veitch, J. A., Arsenault, C., Dikel, E. E., Galasiu, A. D., Gauthier, P., Mancini, S., Nixon, A.
National Research Council of Canada – Construction Research Centre, Ottawa, CANADA
jennifer.veitch@nrc-cnrc.gc.ca

Abstract

1. Motivation, specific objective

Office lighting requirements are written to provide suitable working conditions for the majority of employees while also balancing the need to be energy efficient. Implementing those requirements must balance the interior design features of the space within the budget. The result can be adequate lighting for most people, but possibly not acceptable lighting for employees with light sensitivities. In open-plan spaces, accommodations for those with special needs can include removing the light source from the luminaire directly over the cubicle; relocation to another place, or to work from home. This pilot project tested the feasibility of using an innovative LED luminaire to provide a more suitable lit environment for light-sensitive individuals.

2. Methods

In this repeated-measures experiment, participants worked for two days in each of two very similar rooms, one equipped with the reference lighting system and the other with the test lighting. The order of presentation was counterbalanced. The reference lighting consisted of non-dimmable prismatic-lensed recessed luminaires 0,3 m wide by 1,2 m long equipped with 4000 K LED retrofit tubes having R_a of ~84 (R_f = 84), delivering ~420 lx on the desk. The test lighting consisted of dimmable recessed LED luminaires 0,6 m wide by 1,2 m long with a proprietary optical design diffusing the light from the 3500 K, R_a of ~94 (R_f = 89) LEDs. The large possible illuminance range of ~50 lx to ~800 lx was a deliberate choice for this pilot test. This combination of lighting characteristics was chosen based on the office lighting quality literature.

The participants were 14 adults with light sensitivities, either medically diagnosed or self-identified, and seven individuals from the general population. Scores on the Leiden Visual Sensitivity Scale provided a validation of the status as light sensitive.

Participants did their own work on their own laptops, alone at an assigned location in one room or the other. At 8:45, 11:30, and 15:30 they received an e-mail prompt to complete a questionnaire about their feelings, judgements about the lighting, the room, their own personal appearance, and visual and physical health symptoms; morning questionnaires also asked about their sleep the prior night. The questionnaires used validated scales from prior research. They also completed questionnaires at home on the morning after each second on-site day.

During the testing days, lighting conditions and the height of the sit-stand desks were monitored in both rooms to assess the use of controls in the test room. The team conducted extensive physical measurements of all lighting conditions before and after the data collection period (July – December 2021).

3. Results

The light-sensitive participants were somewhat more likely to use the lighting controls than the general population participants (8/12 light-sensitive participants for whom light level data were available, 3/7 from the general population group). The test lighting room was, on average, lit to a higher level for the general population group (657 lx on the desk) than the light sensitive group (485 lx on the desk) and it was higher for many people in both groups than would be typical of electric lighting in many offices. People who used the controls tended to make a choice in the morning and not to change it throughout the day.

The Office Lighting Survey provides normative data for office occupants' lighting evaluations. The light-sensitive participants agreed that "the light fixtures are too bright" in both rooms, to a higher degree than the normative sample, and agreed more often than the normative sample that the reference (old) lighting was uncomfortably bright for their tasks. A higher-than-normative percentage of the light-sensitive participants judged the test lighting to be better than the lighting in most workplaces. Both the light-sensitive and general population groups had large, statistically-significant effects in which the test lighting was rated as having better lighting quality and it gave a better personal appearance.

The light-sensitive group showed a statistically significant, medium-sized effect for visual symptoms. They started the testing days with a higher average visual symptom score than the general population sample. The visual symptom scores of the general population sample increased very slightly over the workday in both rooms. The light-sensitive group's visual symptoms tended to increase slightly in the reference lighting and to decrease slightly in the test lighting. Furthermore, on days after the test lighting, the light-sensitive group reported visual symptoms that were lower than on days following the reference lighting.

4. Conclusions

This novel lighting solution met the office lighting needs of light-sensitive individuals in this pilot test, reducing their adverse visual symptoms both during the workday and on the following morning. All participants judged the test lighting to have higher lighting quality than the reference lighting. The next step will be to implement the test lighting over a whole floor of an office building, and to evaluate it over a full year.

Session PA1-3
D4/D3 - Road safety

Monday, September 18, 10:50–12:10

OP6

IMPROVING THE DETECTION OF PEDESTRIANS AFTER DARK

Moadab, N.[1] Mao, Y.[1] Fotios, S.[1]
[1] University of Sheffield, Sheffield, UK
n.hafezparastmoadab@sheffield.ac.uk

Abstract

1. Motivation, specific objective

Pedestrians are vulnerable road users. Globally, there are over 270 000 pedestrian fatalities every year, a high percentage of which occur at low light levels. One purpose of road lighting is to enhance the visibility of potential hazards.

If road lighting increases the probability of being seen and/or decreases the reaction time to detection, that would bring reductions in the frequency and severity of pedestrian collisions. There is evidence of this for collisions in general, with studies reporting significant reductions in collisions following the installation of road lighting on unlit roads or after an increase in luminance on an already lit road. The reduction is suggested to be greater for pedestrians than for other road users.

An object is seen when there is sufficient luminance contrast between its surface and the background. But visibility alone is not sufficient for the driver to correctly and rapidly react: that requires the object to be conspicuous. A conspicuous pedestrian is one who is recognised by a driver as a pedestrian, without prior knowledge of their presence in the driving scene. The clothing typically worn by pedestrians is of low reflectance, giving a low contrast and a low conspicuity. To improve their conspicuity, pedestrians could use personal aids such as clothing of higher reflectance or self-luminous devices.

Previous studies show that detection distance is progressively increased (indicating a more effective aid) by adding retroreflective material, self-luminous material, and when using retroreflective bands or light sources around the wrists and/or ankles to mark biomotion. A limitation of such work is that test participants focussed on the given task; they were not distracted as is widely the case in natural driving, and distraction significantly impairs detection.

An experiment was conducted to compare reaction times to the detection of a model pedestrian with variations in lighting, personal visibility aid, and distraction.

2. Methods

The experiment used a scale model road scene in which the observer sits at one end as if looking along the middle of a 3-lane carriageway. A pedestrian appeared at random intervals from behind a parked vehicle parked and proceeded to move along the side of the road. Two further detection tasks (an object suddenly appearing on the road surface, and vehicles ahead changing lane) are not included in the current analysis.

There were four lighting conditions. L1 and L2 represent typical road lighting, with the same SPD and road surface luminances of 0.1 cd/m^2 and 0.9 cd/m^2. L3 was the same as L1 but with an enriched blue in-vehicle light source, the combination giving a similar illuminance at the eye (0.12 lx) as L2, albeit a higher EDI (0.83 lx). L4 was the same as L3 but with the blue light increased to reach an EDI of 80 lx suggested to enhance alertness and improve cognitive performance.

There were three variations in the pedestrian model: a uniform grey (r=0.2, presenting luminances of 0.015 cd/m^2 and 0.142 cd/m^2 under L1 and L2); reflective (the chest area was covered with retroreflective material, presenting luminances of 0.022 cd/m^2 and 0.194 cd/m^2

under L1 and L2); and self-luminous (a flashing LED placed at the centre of the grey pedestrian model, flashing at 2.5 Hz with a luminance of 0.15 cd/m^2).

Three distraction tasks were used: control (fixation upon a moving cross projected onto the rear of the model); visual (the moving cross changed at brief intervals to a single-digit number which the participant reported using a keypad); and acoustic (a randomised sequence of letters was played over a headphone which the participant reported orally).

There were four blocks of trials corresponding to four lighting conditions. Within each block there were three sub-blocks for the three distraction tasks. Block orders were randomised. Each sub-block presented 24 visual stimuli in a randomised order (2 lane changes, 3 pedestrians of each type and 3 obstacles, each repeated thrice) in parallel with the distraction task, with different physical response modes for each type of target. 60 participants were recruited, aged 18 to 31 years.

3. Results

Analysis using ANOVA suggested significant effects of lighting, clothing and distraction ($p<0.001$ in each case) and significant interactions for lighting*clothing ($p<0.001$), distraction*clothing ($p<0.001$) and lighting*task*clothing ($p=0.023$), but did not suggest a significant interaction for lighting*distraction

For changes in lighting, pairwise comparisons revealed a shorter RT with higher luminance (L2 vs L1). The same RT was found for L1 and L3. L4 resulted in the longest reaction time. For changes in the pedestrian model the shortest RT was found with the self-luminous device and the longest RT with the grey pedestrian. Regarding distraction, there was no difference between acoustic distraction and the control, but visual distraction led to longer RT than either of these.

When a test participant was visually distracted their detection response was impaired. The results did not suggest an interaction between lighting and distraction: in other words, a change in lighting did not counter this impairment from distraction. On the other hand, the results suggest significant interaction between clothing and distraction. With grey or reflective clothing, the visual distraction led to a significantly longer RT than for control and acoustic distractions, but with the self-luminous device there were no significant differences between any of the distraction modes. This suggests that impairment due to a driver's visual distraction can be countered by a pedestrian by wearing a self-luminous device that reduced detection latency.

4. Conclusions

This experiment investigated the detection of pedestrians using a scale-model apparatus. A visual distraction task was found to impair detection performance. The impaired detection response (longer RT) when visually distracted was offset by using self-luminous device but was not affected by the change in lighting. For the conditions of this experiment, pedestrian detection when distracted was improved by changes in clothing but was not affected by a change in lighting.

The self-luminous device reduced the RT by 1.5 s compared with the grey model. This is equivalent to a distance of 40 meters when travelling at 60 mph.

OP66

IMPACT OF COLOUR TEMPERATURE AND ILLUMINATION LEVEL ON SAFETY PERCEPTION FOR PARKING GARAGE LIGHTING

Mentens, A.[1], Dotreppe, G.M. [1], Scheir, G.H.[1], Jacobs, V.A.[1,2]
[1] Mobility, Logistics & Automotive Technology Research Centre (MOBI), Dep. of Electrical and Energy Engineering (ETEC), Vrije Universiteit Brussel, Brussels, BELGIUM,
[2] Rectorate, Vrije Universiteit Brussel, Brussels, BELGIUM
Valery.Ann.Jacobs@vub.be

Abstract

1. Motivation, specific objective

Parking garage lighting is often designed to increase visibility for motorized traffic. Lighting conditions can influence perception of safety by increasing the correlated colour temperature (CCT), colour rendering index, vertical (Ev) and horizontal illuminance levels, and illuminance uniformity. It has also been shown that lighting has a positive influence on crime rate, most likely by an increased ability to recognize someone's face.

EN12464-1 and CIE S 008/E:2001 give guidelines about expected lighting conditions but differ in the information provided. For example, the expected horizontal illuminance in a parking garage is 150lx according to EN12464-1, but 75lx according to CIE S 008/:2001. No guidelines are given for CCT values.

Previous studies were performed on scale models that do not provide a complete representation of the actual environment. Some studies used luminaires that were not representative of the spectrum of LEDs commonly used in parking garages, or only took horizontal illuminance levels into account.

This study identifies a suitable range of Ev and CCT for parking garage lighting and identifies combinations with the highest safety perception.

2. Methods

An experiment was held in a parking garage in Brussels, Belgium. The garage is located on the university campus of the Vrije Universiteit Brussel. This location was chosen, as an exploratory survey pointed out that there have been several concerns due to lack of safety feeling in and around the parking garages. A better lighting design compared to the existing installation is believed to improve the safety feeling of parking users.

A suitable Ev and CCT range were determined via an exploratory pairwise experiment with a small group of observers. The observers were asked to submit their preference (in terms of safety perception) between two lighting scenes illuminating two walls (WxH of one wall being 10 m x 4.25 m). Dimmable, tunable white light was installed opposing to the wall. Nine different scenes (combinations of three Ev and three CCT values) were chosen, which results in a total of 36 unique combinations. Observers were presented each scene in left-right and right-left, resulting in 72 combinations. Drywall was installed to avoid light intrusion of surrounding luminaires. The illuminated wall was painted white (RAL 9016), with an estimated reflectance value ρ = 0.85. Illuminance and spectral measurements were carried out with calibrated equipment.

3. Results

The exploratory experiment indicated that high illuminance levels (+75lx) did not seem to increase safety perception. A suitable range of illuminance levels was found with Ev (lx) = {20,40,75}. The Ev values correspond to the standards EN12464-1. In CIE S 008/E:2001 there are no guidelines given about Ev. The CCT range was chosen between 3000K and 5000K, CCT (K) = {3000,4000,5000}, as commonly found in commercial luminaires. In total, 36 unique

combinations are investigated in the currently ongoing full pairwise experiment. The results are expected to be analysed in due time for the conference.

4. Conclusions

An experiment was carried out to identify a suitable range of Ev and CCT values. A pairwise experiment is ongoing to investigate the impact of Ev level and CCT on safety perception for parking garage lighting. The Ev range identified in the exploratory experiment corresponds to values found in EN12464-1. In CIE S 008/E:2001, no guidelines are given about vertical illuminance levels. The CCT range was identified solely on the exploratory experiment, as no guidelines are given in EN12464-1 and CIE S 008/E:2001. This study aims to identify a suitable range of Ev and CCT for parking garage lighting with the highest safety perception.

OP36

CYCLIST FATALITIES INCREASE ON UNLIT ROADS

Uttley, J.[1], Fotios, S.[2], Lovelace, R.[2], Vidal-Tortosa, E.[2]
[1] University of Sheffield, Sheffield, UNITED KINGDOM, [2] University of Leeds, Leeds, UNITED KINGDOM
j.uttley@sheffield.ac.uk

Abstract

1. Motivation, specific objective

Darkness discourages people from cycling. This is likely because potential cyclists feel less safe due to reduced visibility. Poor ambient light makes it more difficult to see hazards such as potholes in the road, and drivers will have more difficulty seeing and recognising cyclists. In many countries it is a legal requirement for cyclists to use cycle-mounted lights after dark as a response to the reduction in visibility, but research suggests a high proportion of cyclists do not use cycle-mounted lights after dark.

Cyclists and potential cyclists may be concerned about crashing if they have to cycle after dark, but are they actually less safe? We assessed data about road traffic crashes that involved a cyclist to address three questions:

1) Does darkness increase the risk of a cyclist crash, after accounting for the time of day and other seasonal changes?
2) Does darkness increase the risk of a cyclist being fatally injured when involved in a crash?
3) Does the absence of road lighting increase the risk of a cyclist being fatally injured when involved in a crash after dark?
4) We addressed these questions for crashes involving at least one cyclist and another vehicle (multi-vehicle crash) and for crashes involving only a cyclist (cyclist-only crash).

2. Methods

Road traffic casualty data from Great Britain were downloaded for the period 2004-2021. These data were filtered to include only crashes that involved at least one cyclist.

To assess whether darkness increases the risk of a cyclist crash we used an odds ratio approach by comparing crash frequencies in case and control periods. The case hour was 18:00-18:59, which for the UK latitude is in darkness for part of the year and daylight for another part. The control hour (14:00-14:49) is in daylight for the whole of the year. Counts of crashes were compared between darkness and daylight conditions in the case hour, and between the same periods in the control hour, using an odds ratio. This odds ratio was adjusted to account for changes in exposure between daylight and dark conditions (i.e. to account for fewer cyclists after dark).

To assess whether darkness increases the risk of a cyclist being fatally injured we compared the ratio of fatal crashes to non-fatal crashes in the case hour when it was in darkness with the same ratio of fatal to non-fatal crashes in the case hour when it was in daylight.

To assess whether the absence of road lighting increases the risk of a cyclist being fatally injured after dark we examined only crashes that occurred after dark, and compared the ratio of fatal and non-fatal crashes when lighting was present with the same ratio when lighting was absent.

3. Results

The adjusted odds ratio for the risk of a crash involving a cyclist after dark was 1.27 (95% CI: 1.22-1.33, $p < .001$) for crashes involving another vehicle and 1.33 (95% CI: 1.08-1.63, p

= .007) for cyclist-only crashes. The odds ratios are significantly greater than one meaning cyclists are more likely to crash after dark than during daylight, for crashes involving another vehicle and also for cyclist-only crashes.

The odds ratio for the risk of a crash after dark involving a cyclist fatality was 1.13 (95% CI: 0.77-1.68, $p = 0.54$) for crashes involving another vehicle and 0.09 (95% CI: 0.01-1.49, $p = .033$) for cyclist-only crashes. The odds ratio for crashes involving another vehicle was not significantly different from one suggesting the risk of a fatal crash was no different after dark than during daylight for such crashes. However, for cyclist-only crashes the odds ratio was significantly less than one, suggesting the risk of a fatal crash was significantly lower after dark than during daylight for such crashes.

The odds ratio for the risk of a cyclist being fatally injured in a crash after dark when no road lighting is present was 7.83 (95% CI: 6.59-9.30, $p < .001$) for crashes involving another vehicle and 2.45 (95% CI: 1.29-4.64, $p = .011$) for cyclist-only crashes. Both odds ratios are significantly greater than one, suggesting that for crashes that do occur after dark, the risk of them being fatal is much higher when no road lighting is present, particularly for crashes involving another vehicle.

4. Conclusions

This analysis confirms the expectation that crash risk for cyclists is greater after dark. In particular, this analysis suggests that the risk of a fatality after dark is greater on roads that are not lit than roads that are lit and hence provides evidence for the benefit of road lighting.

In ongoing work, this analysis is being extended to consider also what factors are likely to increase or decrease the risk of a cyclist crash after dark, and how lighting characteristics such as illuminance and uniformity may be related to crash risk after dark.

This work will contribute to discussion about guidance for the design of road lighting to meet cyclists' needs, a user group currently omitted from CIE 115-2010.

OP5

CYCLISTS ARE INCORRECTLY REPRESENTED IN LIGHTING DESIGN STANDARDS

Fotios, S.[1], Uttley, J.[1]
[1] University of Sheffield, Sheffield, UK.
steve.fotios@sheffield.ac.uk

Abstract

1. Motivation, specific objective

This work concerns cyclists – people using a pedal bicycle or an electrically assisted bicycle (e-bike) for transport. When cycling at night, road lighting should support their needs. Road lighting reduces the risk of traffic crashes and it may encourage more cycling by making cycling feel safer. The provision of road lighting must balance such benefits to cyclists and other road users against the costs, including the unintended consequences of artificial lighting at night including obtrusive light and detrimental impact on some aspects of the nocturnal environment. A lighting designer should be able to expect that the recommendations given in design guidance and standards present optimal criteria for the intended purpose.

There are, however, many uncertainties in the definition of the M-class and P-class recommendations for road lighting, concerning the method for establishing the appropriate lighting class and the lighting conditions specified for that class. Previous discussion by Fotios and Gibbons has questioned the suitability for pedestrians and motorists. In this work we extend that discussion by questioning how the needs of cyclists are represented in road lighting guidance to raise two concerns: (1) they may be included in the wrong lighting class, and (2) the light levels proposed may not be optimal for cyclists' needs.

CIE 115-2020 provides recommendations on light levels in two contexts defined by the type of road user - the M-class for drivers of motorised vehicles and the P-class for pedestrians. While cyclists are noted as a road user, their needs are not specifically defined: they are assumed to have the same needs of lighting as pedestrians. Light levels in the M-class are defined using luminance, feasible when lighting for drivers because they tend to look in a consistent direction (towards the road surface) for which a reasonable estimate of surface reflectance can be made. Luminance is a useful measure because the luminance contrast of an object against the road surface provides a robust estimate of its visibility. Pedestrians gaze is more widely scattered, meaning surface reflectances are unknown at design, and hence light levels in the P-class are defined instead using illuminance. Illuminance characterises the amount of light incident upon a surface, but not the amount of light reflected towards the observer, and hence provides a less precise estimate of object visibility to road users.

Guidance for cycle route lighting tends to refer directly or indirectly to P-class criteria such as that of CIE 115-2010. By inclusion in the P class, cyclists' needs of lighting are characterised using illuminance, with the same range of illuminance as assumed suitable for pedestrians. The pending revision of EN 13201-2:2015 introduces provision for e-bikes and assumes that these are also included in the P-class. These decisions assume that: (1) Lighting criteria for pedestrians are also suitable for cyclists despite their different travel speed and different placement on the road; (2) Cyclists' gaze behaviour is widely distributed and not focussed on the road ahead; (3) Cyclists and pedestrians desire to detect and identify objects at similar distances ahead (and hence subtend similar sizes at the eye) which is unlikely given different travel speeds and different needs for hazard avoidance. Incorrect representation of cyclists in lighting guidance would mean the potential benefits of road lighting are not realised and not correctly balanced against the costs.

We use the results from eye tracking to explore differences in gaze behaviour between cyclists and pedestrians to inform discussion of how cyclists should be represented in guidance for lighting design.

2. Methods

This research used the data from experiments in which the gaze behaviour of pedestrians and cyclists was recorded using mobile eye tracking whilst travelling outdoors, in urban environments, across a range of path types. The output of an eye tracking study for each participant is a video of the scene ahead on which is superimposed a mark identifying their gaze direction at each moment. Analyses of these videos requires the experimenter to determine the object of attention during fixations (when gaze is held static for about 150 ms or more) and this is done by allocation into one of a series of categories, such as the path ahead, peripheral regions, and specific objects (people sitting at benches, standing or moving, other vehicles, other road users, hazards etc).

3. Results

The results show that cyclists and pedestrians have different patterns of gaze behaviour. The road ahead was observed much more by cyclists (43% of all fixations) than by pedestrians (25%): pedestrians frequently looked toward the sides (40%) while cyclists did not (15%). Cyclists also tended to fixate upon other pedestrians and vehicles at greater distances than did pedestrians. E-bike users have not yet been tested: these tend to travel faster than pedal cyclists and evidence from indoor studies with pedal cyclists suggests that different travel speeds lead to different gaze behaviours.

4. Conclusions

Results from eye tracking studies suggest that current guidance does not correctly represent cyclists. Cyclist gaze tends to be focussed more toward the path ahead than it is for pedestrians, who tend to fixate more to the peripheral field than do cyclists. This suggests it is not suitable, or at least unlikely to be optimal, to assume that cyclists have the same visual needs and hence lighting needs as do pedestrians. In particular, it suggests that cyclists' needs from road lighting could be characterised by luminance rather than by illuminance. It is unlikely that cyclists' needs coincide with those of motorists, so rather than assume instead that cyclists are included in the M-class, it is possible that a new class of lighting requirements is needed. This should be considered in the pending revision of CIE 115.

Session PA2-1
D4/D1 - Road lighting measurement
Monday, September 18, 13:20–14:55

OP8

Qd VS Q0 FOR SCALING OF STANDARD R-TABLES IN ROAD LIGHTING DESIGN: THE QUESTION IS WORTH ASKING

Greffier, F.[1], Muzet, V.[2], Boucher, V.[1], Liandrat, S.[3], Schulze, C.[4]
[1] Cerema, Light and Lighting Research Team, Angers, FRANCE, [2] Cerema, ENDSUM Research Team, Strasbourg, FRANCE, [3] Cerema, STI Research Team, Clermont-Ferrand, FRANCE, [4] Technische Universität Dresden, Lighting and Vision Lab, Dresden, GERMANY
florian.greffier@cerema.fr

Abstract

1. Motivation, specific objective

When designing a road lighting installation, knowing the optical properties of the pavement is the best way to optimise quality criteria based on the luminance of the road. Several studies have shown in recent years that using the actual *r*-table of the pavement instead of the standard CIE *r*-tables allows a better adjustment of the average luminance reflected by the lightened road. And in many cases, this optimisation means energy savings.

However, the systematic measurement of the actual *r*-table of a pavement is a rather confidential exercise and the use of standard *r*-tables remains the common practice. Thus, when designing a lighting installation, the most suitable standard *r*-table is chosen according to the specularity of the pavement, which depends on its nature and characteristics. One way to adjust the amount of light as much as possible is then to consider the lightness of the pavement. This optical property can be evaluated using the luminance coefficient in diffuse illumination Qd or the average luminance coefficient Q0. The lighter a pavement is, the more light it reflects, the higher the Qd and Q0 coefficients. If either of these coefficients is known, it can be used to scale the standard *r*-table to better consider the lightness of the pavement and adjust the illuminance to generate a more suitable luminance.

In the current version of CIE 144:2001, it is recommended to use Qd to scale a standard *r*-table. However, in the literature, lighting standards and lighting software, the scaling is done with Q0. It is probably because *r*-tables are usually described using Q0 and the specularity factor S1. In this study, we propose to compare the scaling of standard *r*-tables with Qd or with Q0, both calculated for an observation angle of 1°, and to examine whether one of these coefficients should be used preferentially.

2. Methods

As a first step, different databases of measured *r*-tables were selected: 287 *r*-tables measured in France in the 1990s (database no. 1), 294 *r*-tables measured in Scandinavia in the 1970s (database no. 2) and, much more recently, 57 *r*-tables measured in Germany (database no. 3) and 60 *r*-tables measured in France on pavements typically dedicated to urban use (database no. 4). Each *r*-table was used for lighting calculations considering the seven reference situations of CIE 140:2019. The average luminances thus obtained are the reference values.

In a second step, the standard *r*-table corresponding to each measured *r*-table was used to perform the same lighting calculations by considering two cases: calculations with the standard *r*-table scaled with Qd and then calculations with the standard *r*-table scaled with Q0. The values of Qd and Q0 for scaling were calculated from the measured *r*-table and the weighting coefficients provided in CIE 144:2001. The average luminance obtained in each case for each lighting situation was compared to the average reference luminance by calculating an absolute deviation. Finally, the seven deviations associated with the seven lighting situations were averaged to obtain an overall deviation and to examine which scaled standard *r*-table provided the closest results to those obtained with the measured *r*-table.

3. Results

For database no. 1, the standard *r*-table scaled with Qd (resp. Q0) provides the best results for 202 (resp. 85) of the available *r*-tables. For database no. 2, the standard *r*-table scaled with Qd (resp. Q0) provides the best results for 196 (resp. 98) of the available *r*-tables. For database no. 3, the standard *r*-table scaled with Qd (resp. Q0) provides the best results for 24 (resp. 33) of the available *r*-tables. Finally, for database no. 4, the standard *r*-table scaled with Qd (resp. Q0) provides the best results for 27 (resp. 33) of the available *r*-tables.

For the first two databases, which are the largest and oldest, scaling with Qd is generally the best choice. Things are less obvious for the other two databases, which contain *r*-tables measured on more recent pavements. In order to be able to make recommendations on the use of Qd or Q0, investigations were then carried out to examine whether the choice of either coefficient could be made according to specularity, considering the type of standard *r*-table (R1, R2, R3 or R4). Nothing systematic could be established in this sense.

Therefore, an additional analysis was conducted to examine the values of the overall deviations in more detail. For each measured *r*-table and each of the two corresponding standard *r*-tables (scaled with Qd or with Q0), the number of times the overall deviation was less than 10% was counted. This requirement seems acceptable from an operational perspective and considering the uncertainties associated with the measured *r*-tables.

For database no. 1, the standard *r*-tables scaled with Qd (resp. with Q0) meet the requirement in 87 % of cases (resp. 79 %). For database no. 2, the standard *r*-tables scaled with Qd (resp. with Q0) meet the requirement in 99% of cases (resp. 96%). For database no. 3, the standard *r*-tables scaled with Qd (resp. with Q0) meet the requirement in 91% of cases (resp. 93%). Finally, for database no. 4, the standard *r*-tables scaled with Qd (resp. with Q0) meet the requirement in 82% of cases (resp. 75%).

4. Conclusions

This study was carried out using *r*-tables measured at 1° and a calculation of Qd and Q0 for this geometry. We investigated the scaling of standard *r*-tables to better design road lighting installations when the actual *r*-table of the pavement is not available. We have shown that scaling the standard *r*-tables with Qd is the best option for most surfaces.

This result is particularly interesting. Indeed, Qd is easier to measure than Q0 because the illumination conditions are easier to achieve. This is why there are many more devices on the market that measure Qd than those that measure Q0. These devices currently operate with an observation angle of 2.29° dedicated to the reflectance of road markings. Future research could explore potential correlations between Qd at 2.29° and Qd for other observation geometries more suitable for urban road lighting.

OP30

EXPLORATORY STUDY TO DEFINE NEW OBSERVATION GEOMETRIES FOR ROAD LIGHTING DESIGN

Lebouc L.[1, 2, 3], Boucher V.[2], Greffier F.[2], Nicolaï A.[1], Richard, P.[3]
[1] Spie batignolles malet, Toulouse, FRANCE, [2] Cerema, Light and Lighting Research Team, Les Ponts-de-Cé, FRANCE, [3] University of Angers, LARIS, SFR MASTIC, FRANCE
laure.lebouc@spiebatignolles.fr

Abstract

1. Motivation, specific objective

Performance requirements for road and tunnel lighting are defined in CIE (International Commission on Illumination) or CEN (European Committee for Standardization) documents. These texts specify performance criteria based on the average luminance of the road surface, the overall and longitudinal uniformities of lighting to satisfy the visual needs of users. They also describe the methodology for calculating these criteria when designing an installation or for measuring them on site.

These criteria are defined for only one observation geometry. It considers user's eyes at 1.50m above the road surface with a line of sight at 1° below the horizontal. This geometry is still recommended for a motorist travelling on an interurban road at a speed of between 70 and 90 km/h. However, most street lighting today is located in urban areas, where the average speed is between 30 and 50 km/h. Furthermore, urban lighting must meet the visual needs of all users of public space to ensure the highest possible safety and comfort. This applies not only to motorists but also to cyclists and pedestrians. More and more studies are therefore currently aimed at reconsidering standard geometry to define new ones, more adapted to the urban environment and to the diversity of users.

Our study is therefore conducted in two stages. First, in order to identify the need for light on road surfaces, it is essential to know where users are looking in order to provide them with the right amount of light, the one necessary to make their journeys safe. For this, we use virtual reality techniques coupled with eye-tracking to study the influence of the travel modality (pedestrian, cyclist, motorist) on the observation angle in a night-time urban environment. Secondly, based on the results obtained, we propose to study the evolution of the road lighting performance criteria and the visibility level of a target according to the change of observation angle.

2. Methods

To carry out this study, a virtual environment representing a city and its ring road was created with Unity 3D. The participants had to move around following audio-directional instructions and concentrate on their route as in a real situation. They were given four different roles: pedestrian (speed = 6 km/h), cyclist (speed = 12 km/h), city (speed = 25 km/h) and interurban driver (speed = 75 km/h). Eye-tracking data of 37 participants were collected and analysed.

In a second stage, on-site measurements were performed for two different lighting situations. The road lighting performance criteria and the visibility level were evaluated for three different observation angles. These angles were fixed based on the results obtained during the experimentation in virtual environment. To evaluate the average luminance and the general and longitudinal uniformity when the observation angle is different from 1°, we used the concept of mobile observer. It allows to reconstitute the normalized calculation grid from successive observations. Regarding the visibility level, we have determined it with the Adrian's model which has long been a reference in the CIE documents. We believe that the level of visibility could again become a quality criterion in its own right, especially for defining new observation geometries that could challenge the usual values of average luminance and uniformity.

3. Results

Results of the first experiment show that there appears to be a significant effect of the travel mode on the distance at which the user looks and therefore on the associated average viewing angle. For car drivers on interurban road, we obtained an average observation angle of 1.0°, a result in line with current standards. It is reasonable to expect interesting links between our experiments in virtual environments and real life. For city drivers, we obtained an average observation angle of 2.9°. For cyclists and pedestrians, we obtained angles of 3.1° and 4.2° respectively. As a general and expected trend, we can therefore note that when the travel speed increases, the observer looks further away to anticipate his or her route. Furthermore, our results indicate that the travel mode also influences the dispersion of the users' observation angles.

In the second experiment, on-site measurements were made using observation angles consistent with the results of the first experiment: 1° for interurban driving, 3° for urban driving and cyclists, 5° for pedestrians. We chose the 5° angle to have the same angular increment between our three observation geometries. The main result is that the average luminance on the road surface decreases as the viewing angle increases. Uniformities also tend to deteriorate slightly. However, these trends do not appear to be problematic as the change in geometry does not impact visibility levels, and even improves them when examining their average over the entire standardised measurement mesh.

4. Conclusions

A first experiment was conducted to find out whether the travel mode of users in urban and interurban space has an impact on the angle of observation with which they look at the ground. It is found that as the speed of the user decreases, the angle of observation increases.

On the second experiment, the impact of the observation angle on road lighting performance criteria and visibility is studied. The discussion will focus on the consideration of all users of the public space and whether the visibility level should be reinstated in the performance criteria for road lighting.

At the present stage of our research, we are proposing that 3° and 5° observation geometries, depending on the users’ profile, could be better adapted to urban environments and should be the subject of specific investigations in the coming years. The impacts will concern not only the quality criteria of lighting installations but also the way of characterising the optical properties of road surfaces.

OP69

A NOVEL METHOD FOR FIELD MEASUREMENT OF LIGHT DISTRIBUTION OF MODERN VEHICLE HEADLAMPS

Nilsson Tengelin, M.[1], Källberg, S.[1], Lindgren, M.[1]
[1] Department of Measurement Science and Technology, RISE Research Institutes of Sweden, Borås, SWEDEN
Maria.Nilssontengelin@ri.se

Abstract

1. Motivation, specific objective

Avoiding frequently occurring glare situations is of great importance for comfort and safety when driving a vehicle on the road in the dark. This primarily applies to glare from oncoming traffic, but also road lighting, information signs and road signs can produce high light levels depending on placement and surrounding environment.

A considerable development has taken place in the field of vehicle lighting. Modern light sources usually have higher colour temperatures than traditional halogen, and the spectrum may contain sharp peaks at certain wavelengths. In addition, the light distribution from modern headlamps can generally be tailored with a higher precision producing distinct light images with sharper boundaries and may also include "smart" adaptive functions. Advances have also taken place in the development of road sign materials and road lighting. There is therefore a need for studies on how this affects the glare situation and visibility when driving at night. Furthermore, measuring the distribution and amount of light from vehicle headlamps can provide useful input to assessments of obtrusive light and light pollution along roads.

The headlamps on modern cars are complex and require a communication with the car control system to function which makes it practically impossible to characterize the light distribution in the laboratory without access to a control system simulator. Consequently, there is a need for a method to measure the light distribution of car headlamps with the lamps mounted on the vehicle and therefore a novel method was developed to characterize headlamps in the field.

2. Methods

The idea was, in short, to align a vehicle with the headlights on in front of a large vertical surface and use a luminance camera to capture the resulting luminance distribution on that surface. A large light grey façade was used as the canvas on which the headlights were projected, and a car trailer was used for positioning of the cars, aligning the headlamps at a distance of 25 m from the façade and adjusting the height of the headlamp projection. The luminance camera was mounted on the front of the trailer at approximately the same height as the headlamps.

A narrow beam LED lamp fully characterized in the photometric laboratory was used as a reference to evaluate the reflective characteristics of the façade. By pointing the LED lamp towards different positions evenly distributed over the façade, luminance values for a range of incidence angles were recorded. As the façade exhibited smooth reflectance properties it was possible to obtain a single calibration matrix for converting between measured luminance values on the façade and light intensities at different angles, thus allowing for a full characterisation of the light distribution from the headlights.

The captured luminance images were corrected for the background, aligned, and converted using the calibration matrix. In addition, a mathematical software script was used for removing line artefacts caused by the façade construction (folded aluminium sheets) and lens barrel distortion in the images.

A total of 15 modern cars (model year 2016-2022) were evaluated using the described method. Most of the cars had LED headlamps, but also halogen, Xenon and laser-based headlamps were included in the study. Both high and low beams were measured.

3. Results

A full light distribution was measured for high beam and low beam of 15 different car models from -16° to +16° in the horizontal direction and from -6° to +16° in the vertical direction with a resolution of 0.05°. There was a large variety in the intensity and distribution of the light from different lamps and car models.

For low beam the maximum values ranged from 14400 cd (Halogen) to 43300 cd (LED) and for full beam the maximum values were between 41100 cd (LED) to 186100 cd (LED). Calculations of road sign illuminances using the measured light distributions showed that the illuminance on a sign placed above the road at 150 m could differ up to a factor of 5 between the different car models with low beam headlights. For a warning sign at the side of the road, the mean illuminance at 70 m differed by a factor of 7 for the different models (low beam).

One of the car models also showed a significant colour variation in the projected light distribution around the cut-off, and most likely outside the tolerance set by the ECE-regulations for vehicle headlamps.

For two models the low beam distribution was different when stationary as compared to being in motion, e.g., the cut-off was only a horizontal line without the characteristic elbow-shoulder part of the cut-off.

4. Conclusions

With this novel method we could efficiently and successfully in the field measure the light distribution from headlamps on modern cars, both in low beam (13 models) and high beam (15 models). The light distributions can be used for glare assessments in traffic situations, e.g., from road signs and oncoming traffic. Furthermore, the legibility and visibility of signs can be evaluated. With high beam headlights and high retroreflectivity of the sign, the brightness of the sign may cause an overglow effect with a negative impact on legibility and colour discrimination. For low beam headlights with distinct light distribution and low straylight, the light level on road signs located above the road may be too low for the signs to be readily readable.

OP68

ON SITE PHOTOMETRIC CHARACTERIZATION OF WET PAVEMENTS

Muzet, V.[1], Gublin, G.[1], Rohmer,T. [1]
[1] Cerema, ENDSUM Research Team, Strasbourg, FRANCE
valerie.muzet@cerema.fr

Abstract

1. Motivation, specific objective

The dimensioning or lighting installations are generally done considering that the pavement is dry. However, the road surface can be wet or damp for a large part of the year, resulting in reduced lighting performance with lower uniformities and glare due to mirror reflection.

The CIE technical report 47:1979 contains "standard" wet *r*-tables. These data are more than 40 years old and the wetting method proposed does not allow a pavement to be characterized in different wetting conditions. The measurement for different wetting states is very difficult to achieve because the surface state evolves quickly, whereas the *r*-table measurements carried out in the laboratory are generally quite long (generally from 30 minutes to two hours).

With the current technological developments provided by LED luminaires, it now seems conceivable that lighting might be adapted to the surface condition of pavements, in order to better respond to energy and safety issues. However, to be able to adapt the optics of the luminaires, and thus achieve adaptive lighting, it is first necessary to characterise the photometry of the pavements in the humid, wet and soaked states.

The aim of this work is to propose and validate a simple and pragmatic *on site* wetting protocol which, associated with a rapid portable device, provides measurements of the photometry of pavements for different wetting conditions.

2. Methods

First, a specific protocol able to generate 4 different moisture states of a sample (dry, moist, wet and soaked) was developed and evaluated on laboratory. The measurements were carried out with a portable goniophotometer device which complies with the specifications of the CIE and allows to obtain a complete r-table in less than 1 minute. First results on a database of 13 samples of pavements have shown that there is a great variability in the evolution of the photometry of pavements as a function of the wetting state. The disadvantage of this method is that it is necessary to core the road, which is not always accepted by the managers.

Secondly, a wetting protocol is proposed and tested *on site*. Several outside measurements of the photometry of pavements on different wet states is conducted with the portable goniophotometer device on three different test sites and a total of 8 different pavements with cement concrete, classic asphalts concrete and more innovative pavements (including porcelain chips or with synthetic binder).

3. Results

The obtained results *on site* are compared with the measurements conducted on extracted road samples. The *on site* measurements confirm the great variability in the evolution of the photometry of pavements as a function of the wetting state. For some pavements, the W1 to W4 CIE r-tables describe the pavements well, for others, the specularity is underestimated.

The outside measurements confirmed that, like for the road samples, the average luminance factor Q_0 and the specularity S1 increase with increasing wetting. This appears to be linear between the humid, wet and soaked states but not with the dry state.

4. Conclusions

A characterisation of o*n site* road photometry in different moisture state was conducted in this study and the first results are promising.

The proposed protocol could be used for projects of adaptive lighting depending on weather conditions. With several measured r-tables corresponding to different state of wetting, it is then possible to design adaptive lighting systems able to consider the evolution of pavement reflection properties according to their moisture state.

OP76

TOWARDS A GENERALIZABLE MODEL FOR THE DETECTION OF NON-UNIFORMITIES IN LUMINANCE DISTRIBUTIONS

Schier, K.[1], Niedling M.[1], Schierz, C.[2]
[1] Research Institute for Automotive Lighting, Lippstadt, GERMANY, [2] TU Ilmenau, Ilmenau, GERMANY
katrin.schier@l-lab.de

Abstract

An objective evaluation of the uniformity of luminance distributions has been of strong interest in recent years. For lighting systems designed to illuminate dark environments such as road lighting and automotive lighting, non-uniformities may pose a safety risk as they can potentially lead to masking effects. In decorative illumination unwanted non-uniformities will lead to a reduced quality perception of the luminaire, especially if it is viewed directly. While it takes no effort for humans to detect strong non-uniformities, the development of an objective measurement method independent of application has posed to be a great challenge.

Recently the authors proposed a model that mimics the first contrast processing steps of the human visual system (hvs) to predict the visibility of non-uniformities. The model is based on three steps: modeling the influence of the optics of the eye, neuronal processing of the visual signal and a contrast threshold calculating sub-model. Neuronal processing includes a localized wavelet decomposition of the signal into orientational and spatial frequency channels. The filters of the wavelet decomposition have a resemblance to the receptive fields of the simple cells of the primary visual cortex. The previously proposed model does not regard any area integration effects. However, the area of a stimulus is known to have significant influence on the perceived contrast, especially for contrasts near the threshold. To overcome this problem, we propose adding a divisive normalization step after the channel decomposition. There is strong evidence that divisive normalization is present in many stages of human sensory signal processing. Models implementing divisive normalization have been proven to show a very good correspondence to measurements of contrast threshold changes induced by modulations of the surround of the presented stimulus. This includes psychophysical as well as neuronal measurements of these effects. The output of the divisive normalization step represents a perceived contrast signal, which can then be compared to the predicted contrast threshold. Contrasts exceeding the threshold will be visible to a human observer and are thus kept in the image, contrast below threshold will be eliminated. In order to avoid significant artifacts in the resulting image, this step is conducted in the wavelet domain, before reconstructing the image signal.

To characterize the generalizability of the model to arbitrary luminance image input, two different psychophysically measured datasets are compared to the model's predictions. One dataset containing periodical stimuli and one consisting of simple circular stimuli. In both datasets the detection threshold is measured for changing stimuli size. The model shows good correlation to detection measurements of periodical stimuli. However, a different picture is given when comparing the results to the non-periodic stimuli. The threshold predicting sub-model overestimates the measured threshold without showing any obvious systematic differences. The aim of the model of being generalizable to arbitrary luminance distributions is thus not fulfilled. The reason for the difference between the threshold measured for the different types of stimuli is believed to originate from effects caused by higher areas of visual processing, such as contour integration. The threshold predicting model is only dependent on spatial frequency, luminance and area of the stimulus and cannot account for the observed difference in contrast threshold. The proposed model structure is thus not applicable to arbitrary luminance image input.

A change in model structure is therefore necessary. A possible solution to the problem is using the threshold model to calculate a relative and localized attenuation factor for the spatial frequency channels of the model. At this stage of processing, the effects that are

believed to be responsible for the observed difference in measured threshold are not present. This new structure shows better correspondence to models successfully evaluating the visible difference of compressed images to the original. With the proposed change the model can further be advanced to include more complex processing stages, such as an automated boundary detection of the non-uniformities.

Session PA3-1

D3 - Sustainability 1 and resiliency

Tuesday, September 19, 10:00–11:20

OP23

STUDY ON LIGHTING PLANNING FOR ACTIVE EVACUATION GUIDANCE DESIGN

Akizuki Y.[1], Nagaya R.[1], Yamaguchi H.[2], Hori Y.[1]
[1] University of Toyama, Toyama, JAPAN, [2] National Institute for Land and Infrastructure Management, Tsukuba, JAPAN
Contact email address: akizuki@edu.u-toyama.ac.jp

Abstract

1. Introduction

During a fire, evacuees are required to evacuate quickly, but smoke deteriorates the visual environment, making it difficult to find evacuation routes. In particular, when a space is compartmentalized by shutters being lowered, the spatial configuration differs greatly from that of everyday life, and there have been cases in the past where people were caught in fires because they were unable to find evacuation routes. The number of fatalities due to delayed evacuation accounts for about half of all fatalities, and a lighting plan should actively guide evacuees to evacuation sites so that they can take action even when the visual environment deteriorates.

There are many studies on walking speed and environmental conditions during evacuation. However, there is insufficient knowledge to examine the relationship between visibility and evacuation behaviour using luminance information in a smoke environment.

As an energy-saving measure after the Great East Japan Earthquake in 2011, LEDs have been widely used as a general light source, and are widely used for indirect lighting and architectural lighting. This study aims to understand the effects of the visual environment conditions of evacuation routes on walking time and psychology, and to examine lighting requirements for active evacuation guidance in smoke environments.

2. Summary of Experiment

The experiment was conducted in a maze evacuation room in the Toyama Fire Academy. A C-type guide lighting and LED lightings with a light source surface of 857 mm x 19 mm used for guiding evacuation routes were installed in the experimental space. Experimental conditions included five smoke concentration conditions (Cs = 0 to 2.0), three light source luminance conditions (300, 3000, and 30000 cd/m^2), installation position, installation interval, light source area, and the presence of an evacuation exit guide light.

After acclimatizing a subject to a brightness of the experimental space for at least 5 minutes before the experiment, they were evaluated at the starting point for visibility of the entire road surface, visibility of the evacuation exit guide light, visibility of the next LED guidance lighting, difficulty in moving forward, and tolerance level. Then the subject operated a stopwatch while measuring their walking time to the end of the passage. Finally, the subject was asked to evaluate his tolerance level after walking.

The total of 26 subjects (13 elderly and 13 young adults) participated in the study. Since there were no significant differences in walking time or psychological evaluation results among age groups, the results were handled without dividing them into attributes.

The luminance distribution was measured using a fisheye lens digital camera ThetaZ1 (RICHO) and the luminance chromaticity measurement program developed by NILIM at 3 m, 5 m and 11 m from the location of the evacuation exit guide light. When only the exit light is lit, the light is visible at 3 m in Cs=1, but at 11 m it is not visible because it is assimilated with the surrounding luminance. The luminance distribution result explains the relation CsV=8 in Jin's study between the visibility distance V (m) and smoke concentration Cs (1/m). When the light fixture was on the ceiling, the luminance contrast between the evacuation guide light and its surroundings was poor due to light scattering by white smoke, which was especially noticeable at 3000 cd/m^2.

3. Lighting Requirements for Active Evacuation Guidance

Walking time increases as smoke concentration Cs increases. In many conditions, the average walking time at the highest luminance of 3000 cd/m^2 was significantly shorter. On the other hand, at Cs=0.5, the visibility of the evacuation guide light 11 m away became "invisible" depending on the light source luminance, indicating that the effect of scattered light was greater at higher luminance.

The average walking time for lighting pattern E (floor), which was installed continuously, was shorter in many conditions than lighting pattern C (installation interval 5 m) and pattern D (installation interval 3 m), although no significant difference was confirmed. The next LED visibility "not visible" report rate was significantly different between installation intervals, and most people could see the induction lighting even when the smoke density was Cs≥1.5 if it was continuously installed.

In the comparison of installation positions, the average walking time was significantly shorter in Patterns B (ceiling) and C (floor), in which the induction lighting fixtures were installed horizontally to the direction of travel, than in Pattern A (ceiling), in which the fixtures were installed vertically. In terms of ensuring the visibility of evacuation exit guide lights, it would be better to install guide lighting fixtures in places other than the ceiling surface (floor surface or handrail) in order to effectively guide people to evacuation sites.

4. Ease of Difficulty in Moving Forward

Lighting pattern E, in which guidance lighting is continuously installed on the floor, has the smallest report rate results for "cannot advance" in the evaluation of difficulty to advance. The higher the luminance of the light source, the smaller the report rate, even in high-density conditions where the next LED lighting fixtures for guidance were not visible. This is thought to indicate that the brightness of the evacuation route itself mitigates the difficulty of moving forward.

5. Conclusions

The results of this study indicate that smoke density has a significant effect on evacuation behaviour, and that the thicker the smoke density, the slower the walking speed and the greater the psychological burden. However, the use of high luminance of light source and continuous installation of guidance lighting fixtures can support evacuation behaviour even in a high smoke density environment. In addition to conventional guide lights and emergency lighting, lighting design of evacuation routes based on the luminance distribution of the evacuees' field of vision is necessary to properly and actively "guide" evacuees to exits and "eliminate their sense of anxiety" and will be further studied.

OP86

EVALUATION OF LIGHTING ENVIRONMENT IN A GYMNASIUM FOR VARIOUS ACTIVITIES DURING USE OF AN EVACUATION CENTER

Yamaguchi, H.[1], Oe, Y.[2], Kurobe, M.[2], Akizuki, Y.[3] and Yoshizawa, N. [2]
[1]National Institute for Land and Infrastructure Management, Tsukuba, JAPAN, [2]Tokyo University of Science, Noda, JAPAN, [3]University of Toyama, Toyama, JAPAN,
yamaguchi-h92ta@mlit.go.jp

Abstract

1. Motivation, specific objective

In the case of a large-scale disaster such as a huge earthquake, people may be forced to leave their homes and live in evacuation center such as gymnasiums or halls, which are not their original living spaces. In evacuation center, it is important that evacuees feel safe and secure, especially at night, and the appropriate level of “darkness” is required to allow them to check the safety of their surroundings while not disturbing their sleep. However, gymnasiums, halls, and other facilities are originally designed for sports and various recreational activities, and their lighting design is aimed to provide a sufficiently bright environment, not to provide an appropriately dark visual environment. Our previous studies have shown that if spatial brightness can be predicted, it is possible to predict acceptability for various daily activities in evacuation center, and that spatial brightness can be an indicator of evacuation center lighting environment. Most of the formulas that have been proposed to evaluate spatial brightness are based on photopic luminance, but in order to evaluate brightness for sleep, it is necessary to examine the applicability of these formulas in a mesopic lighting environment. Therefore, in this report, we examined the relationship between spatial brightness and impression evaluation for various assumed activities in evacuation center with various luminance distributions, and examined the spatial brightness prediction method including under the mesopic lighting environment.

2. Methods

The 1/40-scale model (W900 mm x D1000 mm x H325 mm) was set up in a darkened space. On the ceiling, 48 LED lights (correlated color temperature: 3000 K, luminous flux: 190 lm, beam angle: 41.4°) were installed. A total of 20 lighting conditions were selected in consideration of luminance distribution as well as the practicality of gymnasium lighting in the case of a disaster. The luminance condition was set at four levels (0.2, 1.0, 10, and 90 cd/m^2), which is the arithmetic mean luminance in the model space, and a total of 48 conditions were conducted by combining the lighting and luminance conditions. Images with exposure times varied in steps were acquired by a CCD camera, and these images were combined to obtain a luminance image. The luminance images were cropped at azimuth angles of 164° and elevation angle of 117°, which are viewing angles close to the range of observation in the actual model space.

A subject observed the entire interior of the model with his/her jaw fixed through the peephole. After explaining the experiment, the subject practiced evaluation and dark adaptation for 15 minutes. Next, lighting conditions were presented at random by the experimenter, starting with the condition with the lowest luminance level, and evaluation was performed. The lighting conditions of the model space and four assumed activities (normal gymnasium use (playing volleyball), eating or chatting / sleeping/ moving around at night in a shelter) were evaluated in terms of the suitability of spatial brightness and sense of security. Condition setting and evaluation were repeated for each luminance level, with a 15-minute break between each luminance level change. The subjects were 20 students in their 20s.

3. Results

The suitable spatial brightness varies depending on the assumed activities, with the result that the suitable brightness for sleeping is about 1/100th of the arithmetic mean brightness in comparison with the suitable brightness for eating or chatting activities. The evaluation of the sense of safety in each situation except during sleeping was basically highly correlated with the results of the spatial brightness evaluation. However, the results of the evaluation of the sense of safety during sleeping are almost constant regardless of the experimental conditions, and it would be necessary to examine explanatory variables other than spatial brightness. To estimate spatial brightness from photometric values, we first examined regression using arithmetic mean luminance, which is considered the main explanatory variable in various spatial brightness evaluation studies, and confirmed that it can be estimated with a reasonable degree of accuracy. However, a further look at the relationship between the spatial brightness evaluation values at the same level of arithmetic mean luminance showed that the spatial brightness evaluation results varied depending on the non-uniformity of the luminance distribution in the field of view. The accuracy of the spatial brightness evaluation was improved when the standard deviation of the logarithm of the luminance was added to the regression as an explanatory variable to express the non-uniformity of the luminance distribution. The regression equation was also confirmed to be able to estimate spatial brightness ratings, including the mesopic lighting environment.

4. Conclusions

We examined the evacuation center lighting environment using a model space and confirmed that spatial brightness is the key indicator for evaluating the evacuation center lighting environment, where various activities are assumed. To predict spatial brightness under non-uniform lighting conditions, it is necessary to consider the non-uniformity of the luminance distribution in addition to the arithmetic mean luminance, and we examined prediction formulas that can be applied to mesopic lighting environments. In an actual evacuation center lighting environment, it is expected that people will view the lighting environment from various viewing positions and perform various actions simultaneously, it is necessary to consider these points.

OP25

A CROSS-COUNTRY AND SEASON ANALYSIS OF RESIDENTIAL LIGHTING

Aslanoğlu, R.[1], Pracki, P.[2], Kazak, J.K.[1] Yekanialibeiglou, S.[3], Ulusoy, B.[4]
[1] Wroclaw University of Environmental and Life Sciences, Wroclaw, POLAND, [2] Electrical Power Engineering Institute, Division of Lighting Technology, Warsaw University of Technology, Warsaw, POLAND, [3] Bilkent University, Ankara, TURKEY, [4] University of Lincoln, Lincoln, UK

rengin.aslanoglu@upwr.edu.pl

Abstract

1. Motivation, specific objective

Achieving a healthy environment in residential interiors is now more critical than ever, particularly during extreme occurrences like the COVID-19 pandemic. A current and comprehensive viewpoint on residential lighting is required to improve visual comfort, satisfaction, and well-being. It is also important to gather users' opinions and light-related solutions to enhance the current residential standard. Thus, this study investigates residential lighting conditions across four countries including Poland, Sweden, Turkey, and the U.K. in the winter and summer seasons. The light-related factors for visual comfort, satisfaction, and well-being were explored with a comparison among seasons.

2. Methods

A mixed methods perspective was adopted in this study as daylighting and artificial lighting is an intricate concept that needs to be examined from various perspectives using more than one scientific methodology. A survey including 48 multiple-choice and open-ended questions was formed by the research team and was distributed online in the four countries. For the winter season, 500 participants contributed to this study between November 2020 and January 2021. Another 500 participants contributed to the summer season study between June–July 2022. Thus, a total of 1000 participants from Poland, Turkey, Sweden, and the U.K. assessed lighting conditions in their residential areas via online questionnaires. The survey was distributed online via e-mail invitations and/or cross-platform messaging (through a web-based survey tool offered by Google) in the primary languages of these four countries. Besides demographic questions, there were questions about the characteristics of residential buildings and the living areas where participants spent most of their time. Questions about daylighting in their living areas including daylight quantity and its distribution, number of hours of direct sunlight penetration, shading device's type, its position and purpose, the factors related to their satisfaction and dissatisfaction with daylighting conditions were asked. Also, questions about artificial lighting (artificial lighting usage time, its type, system, quantity, uniformity, lamp brightness, the perceived colour of light, colour rendering quality, and the factors related to their satisfaction and dissatisfaction with artificial lighting conditions) were asked. Besides online surveys, 20 online in-depth semi-structured interviews were held between July and August 2022. Five respondents from each country participated in the interviews.

3. Results

The quality of lighting in interiors depends on many factors, such as illuminance, uniformity, correlated colour temperature, colour rendering as well as perceived brightness and sufficiency. As the results of this study show, a correlation was found between daylight satisfaction and its sufficiency. Such as, being very satisfied with daylight quality increased during the summer term in all countries except Turkey. Also, a difference was detected in the correlation between satisfaction with daylighting and the ratio of window-to-floor among seasons. For summer, a significant correlation could not be detected, however for winter, a very low and negative correlation was found. In countries with longer winter seasons, it can be said that window ratios are effective in the satisfaction with daylight. Owing to day length and sunshine duration differences, 36% of the participants in Sweden rated themselves as

very satisfied with daylighting (it was 8% for the winter term). For summer, Sweden is followed by Turkey with 31.2% for daylight satisfaction (this percentage was 32% during winter). 28% of the participants from the U.K. indicated that they were very satisfied with daylighting during summer (it was 20% for the winter term). The percentage of being very satisfied increased from 16% (winter term) to 23.2% (summer term) in the case of Poland.

Similar correlations were found between artificial lighting satisfaction, its sufficiency, and its uniformity. Stronger correlations between satisfaction with artificial lighting, its sufficiency, and uniformity were found in the summer term according to winter-term results. Thus, artificial lighting sufficiency and uniformity have more effect on satisfaction during summer. The correlations between artificial lighting brightness – color rendering index and artificial lighting brightness - artificial lighting uniformity weakened in the summer term. A very low and negative correlation was found between artificial lighting brightness and the number of hours turning on lighting during the summer term. A similar correlation was not found for the winter term. The differences among seasons in terms of artificial lighting indicate that color rendering index and artificial lighting uniformity have a stronger effect on artificial lighting brightness during winter. The differences between summer and winter-term results emphasize the need to pay attention to the lighting design according to the season.

Also, detailed answers were gathered from open-ended questions and in-depth interviews about residential lighting conditions such as removing the shading device and augmenting the characteristics of artificial lighting which were the mostly done adjustments during the COVID-19 pandemic. Also, the most prominent concern among the lighting conditions is visual comfort according to the in-depth interview responses.

4. Conclusions

The study collected data for pointing out the factors influencing visual comfort, satisfaction, and well-being and enhanced the results with in-depth interviews, and open-ended questions. The study gathered subjective assessments and identified the needs and challenging issues regarding lighting in residential areas. Since the study included self-assessments from residential users, its results can be used as reliable recommendations for residential lighting conditions in early planning stages including policymaking, architectural and lighting design as well as future research. As a result, supportive and visually comfortable settings can be developed according to the needs of residential users.

OP37

POST-OCCUPANCY DERIVED USER PROFILES FOR IMPROVED ENERGETIC AND LIGHT DOSE RELATED BUILDING SIMULATION

Weninger, J.[1], Hammes, S.[2]
[1] Bartenbach GmbH, Aldrans, Austria, [2] University of Innsbruck, Innsbruck, Austria
johannes.weninger@bartenbach.com

Abstract

1. Motivation, specific objective

Current lighting designs and simulations are usually based on generalized assumptions about user information, as hardly any information about the target application is available during the building design phase. Predefined models are used for occupancy behavior at the workplace (e.g., 100% probability of presence at the workplace between 07:00 and 20:00). Although these are based on empirical and standardized models, they are formulated as generally valid as possible to achieve broad applicability. However, real occupancy behavior in the workplace turns out to be stochastic rather than deterministic and is largely determined by organization-specific work processes and sociocultural aspects.

Deviations between the assumptions made during the building design phase and the actual situation usually result in performance gaps. In the case of lighting systems, less precise assumptions can lead to the failure to meet energy, comfort, and health-related targets. In addition, generally applicable occupancy models are becoming increasingly unusable due to the rise in home office activities. Improved and application-specific occupancy profiles are therefore needed to achieve better plannability of lighting systems and to reduce performance gaps.

As work processes and social structure have a varying impact on the behavior of individual users, there can be a high variation in occupancy profiles within an organization. In the context of an open-plan office with zoned controllable lighting and presence detection, the artificial light energy demand of a lighting zone is determined from the common presence profile of all users in a given zone. In the case of very different presence patterns, this can lead to lighting zones being used inefficiently in terms of energy. In addition, due to room-related differences in the availability of daylight and highly individual presence times, there can be large deviations between individual users in terms of health-related light doses. This has a strong impact on the dimensioning and performance of health-related lighting concepts. As a result, energy and light dose weighted occupancy profiles are needed to account for the effects of highly individual occupancy patterns on energy demand and health related goals.

After the building has been commissioned, the user behavior and the associated effects on the energy demand can be recorded and evaluated using sensors and data logging (Post-Occupancy Evaluation, POE). Based on POE, measures can usually be derived to take user influences into account after commissioning and to improve system performance (extended commissioning). An example of this is the derivation of more energy-efficient or health-optimized occupancy schemes in an open-plan office with several separate lighting zones. However, due to the current lack of POUs and extended commissioning, user influences on the energy demand and the health-effective light doses remain largely unrecognized or result in resource- and cost-intensive adjustments to lighting controls.

Based on the results several individual studies, this paper aims to present concepts that solve the problems of inadequate occupancy models.

2. Methods

In order to investigate the influence of individual presence profiles on the artificial light energy demand and the health-effective light doses, in an open-plan office for 28 people with nine separately controllable lighting zones, including presence control, daytime colour temperature

control and artificial light control depending on the availability of daylight, the presence at the individual workstation (passive infrared sensor system), illuminance (lux sensor) and the artificial light energy demand (energy meter) were measured within the scope of a long-term study. The real occupancy information obtained was compared with the presence models recommended for the planning context about their effects on the artificial light energy demand via a simulation. By analysing the operating data, it was possible to identify the influencing variables for deviations between real measured data and the model.

To use lighting zones more efficiently in a more energy-efficient or health-optimized way, the presence behaviour of the users was analysed, and improvement measures were derived. Among other things, user profiles weighted according to energy and light doses were determined and improved occupancy schemes were identified by applying mathematical optimisation algorithms.

The measurement data could also be used to generate test data sets, which in turn could be used to create a regression model. This allows a probability function for attendance to be mapped. The resulting occupancy model can be used directly in simulations. The occupancy model determined via the regression procedure was compared with common attendance models.

3. Results

The comparative study of real data and occupancy data shows that work processes such as meetings have a decisive influence on the presence of users at the workplace. It can also be stated that the more degrees of freedom the social structure allows, the more dynamic the occupancy behaviour. Due to the dynamic nature of user behaviour, occupancy patterns can strongly influence the performance indicators of lighting systems and, as a result, intended system designs can fall far short. The performance gaps that occur can therefore be directly attributed to faulty assumptions in the simulation process.

The occupancy models developed in a second study can represent high user dynamics well and thus help to reduce performance gaps between planning and operation. The position, number, and orientation of the sensors as well as data logging over a sufficient measurement period are crucial to derive the occupancy profiles necessary for the regression model. Wireless sensor networks have proven to be a useful tool in this context.

Using the metrologically derived energy and light dose weighted occupancy profiles and applying methods from graph theory, occupancy schemes could be derived to improve performance indicators after commissioning. One occupancy scheme was identified that achieved 30.2% savings in artificial light energy demand and one that improved daily light dose by 11.1% cumulatively across all users.

4. Conclusions

Information on user behaviour offers the potential to improve performance indicators of lighting systems and to close performance gaps by feeding back findings from operation into planning and simulation. The use of well-designed sensor networks including data logging and associated POE can help identify potentials after commissioning and initiate system improvement measures.

Session PA3-2
D3/D6 - Integrative lighting 1
Tuesday, September 19, 10:00–11:20

OP3

LIGHT DIRECTION AT NIGHT INFLUENCES NON-VISUAL EFFECTIVENESS

Broszio, K. [1, 2], Knoop, M. [2], Udovicic, L. [1], Garde, A.H. [3], Völker, S. [2]
[1] Federal Institute for Occupational Safety and Health (BAuA), Dortmund, GERMANY, [2] Technische Universität Berlin, Berlin, GERMANY, [3] The National Research Centre for the Working Environment, Copenhagen, DENMARK
broszio.kai@baua.bund.de

Abstract

1. Motivation, specific objective

Light not only serves for visual needs, but it is also the most important zeitgeber for the circadian system and capable of eliciting non-visual effects like acute alertness or melatonin suppression. In industrialized countries with their 24h-societies humans are increasingly exposed to light at night and more and more people are working at night or in evening shifts. Hence in times when the circadian system expects darkness to function smoothly. On one side sufficient light levels are necessary for work and safety reasons, on the other side it can lead to negative health consequences. Possible mechanisms are circadian misalignment, sleep deprivation and suppression of melatonin. It is known that higher illuminances (E) and higher blue-cyan portion of the spectrum respectively a higher melanopic equivalent daylight illuminance (MEDI) cause stronger melatonin suppression and positively support acute alertness. Further there is building up evidence for the potential of long-wavelength light in eliciting acute alertness without melatonin suppression or disrupting the circadian system. Besides this spectral dependency there are a few studies suggesting spatial dependency by a higher sensitivity of the inferior retina.

In this study we investigated the research question, if it is possible to design the spectral and spatial features of a lighting installation for night shift workers to minimize the melatonin suppression and support best acute alertness.

The following hypotheses were tested:

1. Lighting situations with higher MEDI lead to stronger melatonin suppression and higher acute alertness than lighting situations with lower MEDI.
2. Lighting situations that illuminate the lower half of the retina with light of a higher melanopic daylight efficacy ratio (MDER) than the upper half of the retina at constant MEDI result in stronger melatonin suppression and higher acute alertness than lighting situations that have reversed conditions for upper and lower retina.
3. Lighting situations with a lower MEDI, a higher illuminance, and thus a small MDER result in less melatonin suppression and similar acute alertness as lighting situations with a higher MEDI, a lower illuminance, and thus a larger MDER.

2. Methods

In this study 36 participants (18 female, 18 male) between 18a and 35a, not working night or shift, or traveling across time zones for the past 3 months, are proficient in German, are not color vision deficient, and are either normally sighted or corrected took part. Additional criteria had to be in certain boundaries, like general health, depressiveness, sleep quality, and chronotype. The study complied with the standards of the Declaration of Helsinki and international ethical standards. It was reviewed and approved by the responsible ethics committee. Informed consent has been obtained from all participants.

The study was conducted on weekdays in a lab using a within-subjects design to minimize individual differences effects. The light conditions were counterbalanced (Balanced Latin Square) to reduce carryover effects. At intervals of min. 1 week, the 5h sessions took place for each subject on the same working day.

Participants worked at a control room simulation with two tasks to be performed in parallel to ensure a constant primary direction of gaze, and the corresponding regions of the retina are illuminated. Spectral irradiance was measured using a spectroradiometer at eye position in the direction of gaze. Accordingly, the spatial distribution of illuminance and melanopic irradiance was measured using a luminance camera. Lighting condition 1 has a higher E (>200lx) with 80% from the upper field of view (FOV) and a low MEDI (100lx) with 50% each from upper & lower FOV. Lighting conditions 2 & 3 have a lower E (140lx) with 50% each from upper & lower FOV and a higher MEDI (200lx) with 80% from the upper and 20% from the lower FOV and vice versa.

The 3 conditions were presented for 3h each. The hour before and after the actual light exposure the subjects spent in a dim light (<8lx; 3lx MEDI). Throughout the session, saliva samples were taken and attention tests (psychomotor vigilance task (PVT), the Go/NoGo task, and the n-back test [all auditory]) were performed every hour. Participants rated their subjective sleepiness on the Karolinska Sleepiness Scale (KSS) every hour. Covariables like ambient air temperature, humidity, carbon dioxide concentration and sound level were recorded during sessions and screened for potentially interfering events.

3. Results

The linear-mixed-model statistical analyses of the obtained data were done following the stated hypotheses. We analysed the log-transformed melatonin values, for PVT the mean reaction speed and for Go/NoGo and N-Back the mean reaction time. All measured values were calculated as a difference to the baseline value of each participant after 1h of dim light exposure. First, we compared the data of the lighting condition with 100 and 200lx MEDI (lighting condition 1 vs 2&3) and found a statistically significant effect for melatonin after 2 and 3h of exposure, for PVT after 2h of exposure and none for Go/NoGo and N-Back. Second, we analysed the data of the two lighting situations with the same overall MEDI and different spatial distributions (lighting condition 2 vs. 3). Here we found a statistically significant effect for melatonin after 3h of exposure, none for PVT and Go/NoGo, but for N-Back after 3h exposure.

4. Conclusions

The outcome of this study suggests that the inferior FOV can be illuminated with light with higher MDER than the superior FOV in nightly long-term applications, to meet the initially set criteria to contribute to the maintenance of health during night shift work. Or the other way around, that it is more important for melatonin suppression which spectral composition the light form the superior FOV has than from the inferior FOV. This could influence lighting design and lead to guidelines for night shift workplaces, especially for workplaces where main viewing directions are known and constant for prolonged periods. This would enable the lighting designer to tune not only the overall spectrum but also the spatial distribution and lead to health-promoting lighting recommendations for workers in control centers, control rooms or similar workplaces.

OP53

THE EFFECT OF S-CONE ON LIGHT-INDUCED ALERTNESS BASED ON ACCURACY STUDY OF EEG EVALUATION METHOD

Huang Y., Dai Q.
Institute of Future Lighting, Academy for Engineering & Technology, Fudan University, Shanghai, 200433, CHINA
qidai@fudan.edu.cn

Abstract

1. Motivation, specific objective

Lighting has been shown to have non-visual biological impacts on human being, including the regulation of alertness. Studies have found that light exposure with high photopic or melanopsin illuminance (ipRGCs-related) can directly improve acute alertness and indirectly affect attention, work efficiency and performance. However, the contribution of visual and non-visual photoreceptors to alertness, especially the contribution of S-cone visual photoreceptor, are still controversial. To detect the mechanism of alertness effect, an accurate method for quantifying alertness is fundamentally needed. Though brain electrophysiological (EEG) method is considered to be more accurate compared with the objective Karolinska Sleepiness Scale (KSS) method, currently, there are different EEG frequency ranges as indicators for alertness detection, including delta (δ), theta (θ) and beta (β). It was suggested the EEG algorithms, such as (δ+θ)/β, may also be the possible indicators. However, there's no consensus on which EEG evaluation method is more closely associated with the light-induced alertness. This uncertainty hinders the lighting research that aimed at understanding the mechanisms underlying the effect of light on alertness. Therefore, the objective of this study is to investigate EEG evaluation methods that can accurately detect differences in alertness effect, and use validated EEG methods to exam the contribution of S-cone to alertness.

2. Methods

To investigate the accuracy of the EEG evaluation methods, we adopted four lighting conditions with large difference in light intensity, which could achieve significantly different impact on alertness. Light-exposure levels included 30, 100, 300 and 600 lux. The validation of EEG evaluation method could be proved if it could detect the alertness difference among each condition. We also designed a pair of lighting conditions which have equivalent light intensity (300 lx), activation on M-, L-cone, rod and ipRGCs, but large difference on S-cone-related cyanopic illuminance (109.5% difference). The effect of cyanopic illuminance on alertness was examined by comparing alertness indicators using the validated EEG method. All lighting conditions were in white color with reasonablely high color rendering index.

Human-factor studies were conducted, which employed a within-subject, sex and order counterbalanced design. Sixteen participants (aged 18–30) were exposed to all four light intensity conditions for 3 h in the evening, while another sixteen participants were exposed to two contrast conditions with the same photopic illuminance but different cyanopic illuminance. Assessment of subjective alertness using KSS method and records of waking EEG data repeated every 60 minutes during the 3-h lighting session. The power spectra of the EEG signals were computed using the fast Fourier transform and extracted δ (1-4 Hz), θ (4-7 Hz), and β (15-20 Hz) frequency bands. The (δ+θ)/β ratio was calculated as a potential EEG algorithm. P values < 0.05 were considered as significant.

3. Results

The EEG evaluation showed that the power within the β frequency range was significantly lower under the 30 and 100 lx lighting condition compared to 300 and 600 lx across 3-h light exposure. Similar results could be found using (δ+θ)/β algorithms. However, based on the δ+θ frequency range, the difference of alertness among each condition was only detected after 1

hour light exposure. No significant difference was observed in KSS scores under different illumination levels. Therefore, the evaluation method using KSS and (δ+θ) frequency range may less sufficiently accurate for measuring the impact of light on alertness compared with that adopting β frequency range and (δ+θ)/β algorithms.

Based on the effective EEG methods, we compared alertness effect of two lighting conditions with the same photopic illuminance but different cyanopic illuminance. After 1 hour and 2 hours light exposure, the power within the β frequency range under low cyanopic illuminance lighting condition was significantly lower compared with that under high cyanopic illuminance lighting condition, indicating higher alertness effect when cyanopic illuminance is in lower level. The results based on (δ+θ)/β algorithms was consistent with this finding. These EEG results indicates that the S-cone also plays an important role in light-induced alertness effect.

When comparing the alertness under lighting condition with 300 lx and 600 lx, no significant difference was observed neither using EEG nor KSS evaluation. While there's significant difference of alertness between two lighting conditions with different cyanopic illuminance, which were both at 300 lx. These findings indicated the effect of light intensity on alertness may be limited, suggesting that light intensity in high level may lead to saturated effect. Cyanopic illuminance showed more considerable impact on alertness compared with light intensity. Therefore, it's possible to provide high level of alertness effect on individuals by manipulating cyanopic illuminance, while avoid high energy consumption and glare elicited by light intensity increasing.

4. Conclusions

In this study, we found that adopting β frequency range and (δ+θ)/β algorithms are sufficiently accurate EEG evaluation method for detect the impact of light on alertness. While the accuracy of evaluation using KSS or (δ+θ) frequency range may be limited. Based on the validated EEG processing method we proved in this study, it was found that S-cone-related cyanopic illuminance had significant impact on alertness, lighting condition with lower cyanopic illuminance showed higher alertness effect. Compared to the lighting approach by increasing light intensity for alertness improvement, manipulating cyanopic illuminance could achieve better balance in efficient energy, visual comfort and considerable alertness effect in indoor lighting design.

OP52

INSIGHTS INTO SPECTRALLY RESOLVED LIGHT-DOSIMETRY DATA

Hartmeyer, S. L.[1], Andersen, M.[1]
[1] Laboratory for Integrated Performance in Design, School of Architecture, Civil and Environmental Engineering (ENAC), Ecole Polytechnique Fédérale de Lausanne (EPFL), Lausanne, SWITZERLAND
steffen.hartmeyer@epfl.ch

Abstract

1. Motivation, specific objective

Light enables visual perception of the world and has a fundamental role in regulating biological rhythms as well as acute physiological and behavioural functions. The patterns of light we are exposed to on a daily basis (personal light exposure) are highly complex signals resulting from the interaction between the light provided in our immediate environment and our behaviour within this environment. Not only the amount of light but also the spectral composition of light arriving at the eye fluctuates over time, depending on the light sources and reflecting materials in the environment. As such, personal light exposure can be thought of as a “spectral diet”. Measuring the spectral diet of individuals or groups of people in the real world (light-dosimetry) may help to identify potential for lighting interventions, to validate lighting design decisions, and to understand how building features shape personal light exposure, which is crucial in understanding how modern living can be better aligned with human biology.

For measuring spectral diets in field-studies, wearable light sensors (dosimeters) with a sufficient spectral resolution are required to recover the spectral quality of the light measurements. Here we present first insights into data collected with a novel dosimeter (Spectrace) measuring spectral irradiance in 14 channels along the visible wavelength range. This dosimeter was used in the context of an intervention study investigating the effects of a tuneable lighting system on highschool students in Iceland, with the aim to validate and explore the impact of the lighting intervention on students’ spectral diet.

2. Methods

The study was conducted during the schoolyear 2021-2022 in a highschool in Reykjavik, Iceland, including two experimental conditions implemented in the school’s classrooms: a dynamic bright light setting (600-1000lx, 3000-4000K) and a static dim lighting setting (300lx, 3000K) using tuneable LED fixtures. The experimental lighting conditions were installed after a baseline period under the previous lighting conditions and remained in place for the entire schoolyear. Assessments of multiple parameters, including the student’s personal light exposure, were made during four one-week periods across the schoolyear. Spectrally resolved personal light exposure was continuously monitored with the Spectrace dosimeter in students of two classrooms (bright light and dim light). The sensor was worn at chest level and set up with a recording interval of 1 minute.

3. Results

Due to significant dropouts in participants across the four measurement periods, we only analysed the light data from the first (baseline) and the second (intervention) measurement period, for which data from 24 and 17 students, respectively, were available. The raw 14-channel sensor data from the Spectrace dosimeter was converted to spectral irradiance by means of a sensor specific calibration procedure, interpolated to 5nm resolution, and normalized. Then the spectral data was split into data during school times and leisure times, grouped per period (baseline, intervention) and condition (bright, dim), and the median spectrum of each group was calculated. As expected, during school times, the median spectrum was similar for the baseline period but different during the intervention period, where the median spectrum in the bright and dim light grouping corresponded to the 4000K

spectrum and the 3000K spectrum of the bright and dim light conditions, respectively. During leisure times, median spectra were similar between conditions for each measurement period, with a larger fraction of daylight spectra during the baseline period (early October) than during the first intervention period (late November) for both conditions.

To further analyse the spectral diets during school times, unsupervised clustering on the combined data was performed. The resulting clusters were identified by correlating the mean spectrum of each cluster with different known light source spectra (e.g., daylight, standard illuminants, commercial light sources etc.), including the study condition light source spectra (i.e., 4000K and 3000K). The clustering analysis revealed five main types of spectral clusters: cool white LED, warm white LED, fluorescent, daylight, and a broad spectrum most likely corresponding to a mixture of daylight and electric light. As before, the two LED spectra matched the study condition spectra. The personal light exposure timeseries data of each participant was then tagged with the corresponding cluster index and compared between periods and conditions, confirming that spectral diets were similar between conditions for the baseline period but not for the intervention period, as intended.

4. Conclusions

This study is one of the first to collect personal light exposure data at a relatively high spectral resolution. While spectrally resolved light-dosimetry is still in its infancy, the interest for such data is high and various projects are underway to develop spectrally resolved dosimeters for use in light-dosimetry studies. Here we show first insights into the spectral diet of participants in an intervention field-study, demonstrating that spectral types can already be successfully identified and differentiated using simple clustering techniques. Currently, we are developing more refined analysis and quantification methods for this kind of data to harness its full potential for informing about the spectral diets of individuals or specific subject populations. Taken together, with this first data, we show that spectrally resolved light-dosimetry is feasible and provides unique and novel insights into our daily life with light.

OP16

INTEGRATIVE LIGHTING IN OFFICES: RESULTS FROM FIELD MEASUEMENTS AND ANNUAL SIMULATIONS

Pellegrino, A.[1], Lo Verso, V.R.M.[1], Valetti, L[1], Giovannini, L.[1]
[1] Department of Energy 'Galileo Ferraris', TEBE Research Group, Politecnico di Torino, ITALY
anna.pellegrino@polito.it

Abstract

1. Motivation, specific objective

Over the past 25 years, research concerning the human responses to light has been largely expanded; currently, there is strong scientific evidence that light is not only essential for vision, but it also affects the biological functioning of people and has an important impact for human health and performance. Numerous studies have demonstrated that light also influences circadian rhythms, neuroendocrine functions, and neurobehavioral responses. These types of responses have been defined as non-visual and non-image-forming (NIF) effects of light. In this context, two dedicated circadian metrics have been proposed to estimate and quantify the non-visual effects of light: (i) the 'Circadian Stimulus' (CS) model; (ii) the 'melanopic equivalent daylight illuminance' (m-EDI) and the melanopic daylight equivalent ratio m-DER. Despite the new metrics are not yet adopted in standards for lighting design, the m-EDI has been included in the WELL protocol, which is specifically devoted to promoting the well-being of people in buildings and communities.

Integrative lighting, which integrates both visual and non-visual effects of light, is particularly crucial in office buildings, as it strongly affects the alertness and the productivity of workers. However, despite the growing knowledge concerning integrative lighting and NIF effects of light, current design approaches and standards for indoor lighting are mainly intended to ensure visual requirements and to maximize energy efficiency. Consequently, they are usually expressed in terms of photopic quantities, without taking non-visual responses to light into account. Therefore, additional efforts seem to be needed to define specific and agreed recommendations that address both photopic and melanopic issues.

In this frame, the paper presents results from a study on integrative lighting that was carried out in some real office rooms (both cellular and open plan), located in the university 'Politecnico di Torino' in Turin, Italy. Both electric lighting and daylighting conditions were analysed, with the goal of outlining a framework of the integrative lighting conditions that can exist in typical office spaces, considering the whole occupancy time-frame. Further objectives of the study were: (i) to check the compliance of the lighting conditions with the requirements currently reported in recent literature and in the WELL protocol; (ii) to critically analyse the requirements with respect to their applicability in existing buildings; (iii) to assess the influence on integrative lighting played, in the analysed spaces, by respectively electric lighting and daylighting.

2. Methods

Different spaces were selected so that they were representative of typical offices and lighting/daylighting systems: different window area and orientation and both fluorescent and LED lighting systems were considered.

The study relied on a combination of approaches:

(i). field measurements, to characterise photopic and melanopic illuminances in the selected office rooms due to the electric lighting system only;

(ii). simulations, to evaluate photopic and melanopic illuminances on annual basis, using the LARK simulation tool within Grasshopper, so as to account for the dynamic variation of daylight conditions over the course of the year and the behaviour of the occupants (occupancy profile, use of blinds);

(iii). combination of experimental and numerical results, to analyse the lighting conditions that results from the integration of daylight and electric light.

3. Results

Results were presented for each lighting condition (electric lighting and daylighting), both separately and in combination:

- electric lighting, aimed at analysing if the lighting systems in the various spaces meet the photopic requirements and the corresponding circadian performance in terms of m-EDI and m-DER
- daylighting, aimed at analysing the daylighting amount in the various offices in terms of spatial daylight autonomy and in terms of m-EDI over the year to verify the percentage of space and time during which daylight alone is sufficient to satisfy the circadian requirements
- combination of daylighting and electric lighting, aimed at assessing the final performance of the various offices in terms of integrative lighting on an annual basis.

4. Conclusions

Based on the results, considerations and conclusions were drawn regarding the following aspects:

- level of integrative lighting reached in the various offices and compliance with WELL protocol
- impact of daylighting on the achievement of WELL recommendations on annual basis, as a function of room size, window area, and orientation
- impact of electric lighting on the achievement of WELL recommendations, as a function of the luminaire type (mounting position and photometric solid) and the spectral characteristics of the light emitted.

Session PA3-3
D1/D3 - Augmented and virtual reality
Tuesday, September 19, 10:00–11:20

OP63

CHARACTERISING HEAD-MOUNTED DISPLAYS BASED ON VISUAL ASSESSMENT

Lee, C.[1], **Ou, L.[1]**,
[1] National Taiwan University of Science and Technology, Taipei, TAIWAN
M11025017@mail.ntust.edu.tw

Abstract

1. Motivation, specific objective

While virtual reality (VR) technology and its applications are growing exponentially over the years, there have been few studies of colour in VR. This is mainly due to challenges in measuring colours shown on a head-mounted display (HMD), a typical display device for creating immersive VR experiences. Without accurate colour measurement, it will be hard to create a reliable characterisation model that relate RGB values of colours shown on an HMD and the CIE XYZ values, and it will also be difficult to reproduce colours accurately on the HMD for research of colour and imaging. Colour measuring instruments specifically for HMDs have been available for purchase for the past few years. However, such instruments carry a hefty price tag and thus are considered an expensive solution by some researchers of this field.

To solve the issues described above, the present study proposes a new approach to characterising HMDs. The approach is based on visual assessment of colours required for establishing a display characterisation model, without using any instrument to measure colours on the HMD.

2. Methods

The display characterisation model that the present study adopts is the gain-offset-gamma (GOG) model. The GOG model is a most widely used two-stage model originally developed for cathode-ray tube displays but was later found to perform well for some types of liquid-crystal displays (LCDs). The GOG model utilises a nonlinear and a linear stages of data transform, both in the form of a 3x3 matrix. Conventionally, the nonlinear stage requires measurement of CIE tristimulus values for colours of the display's RGB channels, in order to establish the opto-electronic transfer functions (OETFs) for each channel in terms of gain, offset and gamma values. The OETFs then transform display digital counts for any given colour into corresponding RGB values, which are then converted to CIE tristimulus values in the linear stage. This conversion matrix also requires measurement of tristimulus values for the display peak white and the maximum RGB colours.

The basic idea of the new approach presented in the present study is to replace instrumental measurement conventionally required for developing a GOG model, with three visual assessment techniques, partition scaling, unique hue judgement and colour matching:

- The partition scaling method is used to estimate lightness values of colours for RGB channels in order to determine gain, offset and gamma values in the OETFs. Partition scaling is a psychophysical procedure based on bisection tasks and can derive an interval scale of a psychological attribute from an observer's visual evaluation of given stimuli, such as lightness. In the present study, the observer is shown with three coloured discs, all selected from one of the three RGB channels, aligned horizontally on the screen. The coloured discs at the two ends have the highest and lowest lightness of a selected lightness section. The positions of the two discs are randomised. Observers are asked to adjust the middle disc until it appears to have an average lightness of the discs at the two ends. In this study, each of the RGB channels is divided into eight lightness sections, i.e., there are seven lightness boundaries, and the lightness values for these boundaries are estimated by the results of partition scaling. These lightness values are then used to determine the OETFs in the GOG model. In addition to RGB channels, the achromatic

channel is also included in the partition scaling to improve performance of the characterisation model.

- The unique hue judgement method is for hue correction in the characterisation model of the display. The present study uses colour stimuli at four or five levels of lightness to evaluate the four unique hues, red, yellow, green, and blue. The hue indicators and hue-related difference obtained from this session are then used to correct the GOG model.
- The colour matching technique is used to match colours shown on a calibrated LCD to the HMD's peak white and the maximum RGB colours, to estimate and determine these colours' tristimulus values. This means that the linear stage's 3x3 matrix that conventionally requires measurement of XYZ tristimulus values can be replaced with the results of colour matching.

These visual assessment techniques are first implemented to an LCD as a pilot study, which includes 30 observers. This is followed by the main experiment, using the same visual assessment sessions for an HMD, with 20 observers participating. The ultimate goal of the main experiment is to develop a GOG model for the HMD. The colour stimuli shown on the HMD are generated in a virtual environment with unlit shader to avoid unwanted shadow effects.

3. Results

The experimental results of the pilot study show great predictive performance of the GOG model for the LCD, with a small CIELAB colour difference comparable to the performance of a GOG model based on instrumental measurement for the same display. This LCD is treated as a reference display during the colour matching session for the HMD in the main experiment.

Due to differences in colour gamut (and in colour volume) between the LCD and the HMD, the colour stimuli used in the partition scaling session of the main experiment are selected within a shrunk gamut of the HMD. This means that although the GOG characterization model for the HMD can predict well within the shrunk gamut, it is unclear whether the model can also predict accurately for colours outside the shrunk gamut. A solution to this will be to use an LCD with a colour gamut larger than the HMD.

4. Conclusions

This study proposes a visual approach to developing a characterisation model for HMDs using visual assessment techniques including partition scaling, unique hue judgement and colour matching. These methods can be considered an alternative to conventional instrumental measurement. The promising results show that the new approach is particularly useful when there are limitations in the use of measuring devices for an HMD.

OP67

RELIABILITY OF SPACIOUSNESS EVALUATION FOR ROOMS WITH WINDOWS IN AN EXPERIMENT USING HEAD-MOUNTED DISPLAY VIRTUAL REALITY

Miyake, H.[1], Horiuchi, Y.[2], Nishihara, S.[2], Yamaguchi, H.[3], Yoshizawa, N.[2]
[1] Arup, Tokyo, JAPAN, [2] Tokyo University of Science, Chiba, JAPAN,
[3] National Institute for Land and Infrastructure Management, Tsukuba, JAPAN
hiroyuki.miyake@arup.com

Abstract

1. Motivation and specific objective

Spaciousness is an important factor of a space for its occupants' comfort and health. For subjective experiment for spaciousness evaluation, virtual reality (VR) using a head-mounted display (HMD) is a powerful tool. By adopting VR, required material can be reduced, many combinations of conditions can be created, and a subject can virtually compare two physically-distant spaces. However, the spaciousness perceived via VR is not always the same as the real space.

In previous research concerning rooms without windows, the reliability of spaciousness experiments using VR and HMD has been evaluated, but there exist no studies for rooms with windows. The merit of deploying VR for experiments in rooms with windows is considerable, as the exterior environment (weather, planting and ageing of materials etc.) is a natural phenomenon which is difficult to control and not reproducible. With VR, natural conditions can be controlled, kept the same in the experiment and be changed according to the research requirements.

In this study, we conducted a subjective experiment to evaluate the spaciousness of VR spaces; specifically, we emulated real spaces used in a past experiment. The purpose of that previous experiment was to study the relation between the perceived spaciousness, dimensions, and lighting conditions of a room. Through comparing the spaciousness in VR with the spaciousness in the original space of the previous experiment, we evaluated whether or not there were differences.

2 Method

Whilst this was a VR experiment, it was physically conducted in a room at Tokyo University of Science in Chiba, Japan, Nov and Dec 2022. The real original space was an experimental room at the Building Research Institute in Tsukuba, Japan. The room comprised six windows which could be completely hidden with opaque roll screens, 12 dimmable base-lighting fixtures, and the dimensions are 5.1x11.5x2.8m rectangular which is separable with a curtain at the centre). Through the windows, trees and sky could be seen by the subjects. By employing the roll screens, curtain, and dimming system, we prepared 21 comparative conditions. Using the magnitude estimation (ME) method, 19 subjects (students in their 20s) were asked to evaluate spaciousness and brightness of the comparative conditions in reference to standard conditions in VR; the conditions were identical to those used in the previous experiment.

To create the VR, we used Rhinoceros, Unreal Engine 4 and Oculus Quest. Since the maximum luminance level which could be displayed with Oculus Quest was 100cd/m^2, it was impossible to reproduce the real luminance value outside of the windows and the direct sunlight coming through the windows. We adjusted the VR luminance to perceptually match the real luminance on the two premises. First is the normalised response curve in the perception of luminance, which means that relative response can be standardised between 0 and 1 with the sigmoid function. In this way, the real luminance (which has a wide range and includes high values) and the reproduced luminance in VR (which ranges only between 0 and

100cd/m2) are converted into relative values in the same range and can be compared. Second is the separation of interior and exterior. The difference in luminance between the exterior light and interior light was huge, and it was unfeasible to apply the normalisation function at the same time. Since eyes have different responses when looking at interior and exterior environments, we divided the view to interior part and exterior part, then compared the converted luminance values separately.

Through this adjustment process, we repeatedly measured the luminance output value in HMD and fed back to the lighting and material setting in Unreal Engine to match the output to the measured values in the real space. To acquire luminance images, we used L-CEPT (Luminance & Colour Environment Photometric Tool) with a calibrated CCD camera. After adjustment, deviation of the converted value of VR luminance was found to be less than 15% compared to the converted value of real luminance.

3. Results

We compared the reported spaciousness value of VR space with the value of the original real space. Using the Wilcoxon rank sum test or Welch's t-test, considering the normality and homoscedasticity, for 20 conditions in 21, the null hypothesis was not rejected at the 5% significance level, i.e. the obvious difference could be found only in one condition. In that condition, the spaciousness value in VR was lower than the original real space, in line with previous research.

Regarding brightness, only for 8 conditions in 21 was the null hypothesis not rejected at the 5% significance level. In the other 13 conditions, the brightness of VR was lower than the original real space. There was a positive correlation between the deviation and the original real space's average luminance (R^2=0.48). In the six of seven conditions where the average luminance (excluding the part where we see the natural light directly) of the real space was over 200 cd/m^2, the reported brightness of VR was significantly lower than the real space.

4. Conclusion

The experiment results confirm that the reproducibility of spaciousness in VR is at a useful level, although there was a case where the VR spaciousness was lower. Regarding brightness, VR brightness was lower in half of the conditions. The result was consistent with the previous study's formula. The coefficient of the formula showed that, when the lighting environment's difference was only in the quantity and the distribution of luminance in the space was the same, the effect of dimensions was 13.3 times higher than the effect of brightness. This could explain why, in 12 of the 21 conditions in this VR experiment, the spaciousness was not different, despite the brightness being lower.

Further studies are required to clarify when and how the VR spaciousness is lower than the real space in a specific condition, and why there are conditions where VR brightness is lower. It is also necessary to develop the adjustment method to make it closer to the real world and thus make VR reliable for future experiments.

OP13

THE EFFECT OF AMBIENT LIGHTING IN THE USAGE OF AUGMENTED REALITY

Mou, X.[1], Mou, T.S.[2]
[1] Zhejiang Smart and Health Lighting Research, Qingshan Lake City, CHINA
[2] Zhejiang University, Hangzhou, CHINA
mollymou@sensinglab.org

Abstract

Augmented reality (AR) technology has become increasingly popular in recent years, with applications ranging from education to manufacturing as well as healthcare. However, one factor that can significantly impact the quality of AR experiences is the ambient lighting conditions in which they are viewed. This paper will explore the effects of ambient lighting on AR image quality, with a focus on light level and color temperature.

The quality of AR images can be affected by the ambient lighting conditions in which they are viewed. The color temperature of the ambient lighting can affect the way colors are perceived in the AR image. For example, if the ambient lighting is in a warm tone (lower CCT), it may make higher CCT colors of the AR image appear more muted or washed out. Conversely, if the ambient lighting is cool, it may make warm colors in the AR image appear more vibrant or saturated.

To mitigate the effects of ambient lighting on AR image quality, Most AR devices may use sensors and algorithms to increase the brightness and contrast of the AR image in real time. Additionally, AR developers may optimize their software to perform well under a variety of lighting conditions. In this paper, we will address the effects on AR image quality due to various ambient lighting conditions. The light levels and correlated color temperature are mainly studied.

1. Motivation, specific objective

There are several objectives of this study:

1. Explored the requirements of lighting in various types of AR. In this paper, we selected two types of commercially available AR devices for evaluation.
2. Investigated the effects of ambient light level in the usage of AR, for example, the see-through image's contrast ratio.
3. Studied the effects of chromaticity values and color gamut under different ambient lighting conditions in the usage of AR.
4. The level of effects of ambient lighting in the usage of AR under different Field of Views.

2. Methods

In this paper, we selected two commercially available AR devices as examples to measure the spectral irradiance and see-through spectral transmission ratio of the virtual image. We evaluated the image contrast and display colour capabilities under various lighting conditions including CIE illuminant A, FL-1 and D65. Three ambient luminance 100 cd/m^2, 300 cd/m^2, and 800 cd/m^2 were selected to mimic the ambient illumination in AR applications. The optical measurement system mimics the optics of the human eye to measure the AR's virtual image luminance, chromaticity coordinates as well as colour gamut area. The transmittance of the AR devices was also recorded.

The results were analyzed to evaluate the contrast, colour drift, and colour gamut areas of the two AR displays based on the above lighting conditions; and we discussed the impact of different areas in the Field of Views.

3. Results

1）Bright ambient light can significantly diminish the contrast of the virtual image.

> Light level can have a significant impact on the quality of AR images. If the lighting is too bright or dim, it can make it difficult for the AR device to accurately detect and track the physical environment. This results in the AR image appearing distorted, shaky, or not aligning properly with the real world. In low light conditions, AR devices may struggle to detect features in the environment, resulting in a loss of tracking accuracy. This can lead to jittery or unstable AR images, which can negatively impact the user experience. On the other hand, in very bright lighting conditions, the AR image may appear washed out or overexposed, making it difficult to discern details in the image. The measured contrast ratio of the virtual image was significantly reduced by bright ambient illumination.

2）The RGB primary colors in the virtual image bleached in ambient light and the colour gamut area was reduced.

> Color temperature refers to the perceived warmth or coolness of a light source, with lower color temperatures (around 2700K) appearing warmer and higher color temperatures (around 5000K) appearing cooler. The results indicated that warm ambient lighting could make cool colors in AR images appear more muted or washed out. When the ambient lighting is warm, it was difficult to discern blue or green objects in the AR image, as these colors appeared less vibrant. Conversely, cool ambient lighting made warm colors in AR images appear more vibrant or saturated. When the ambient lighting was cool, red or orange objects in the AR image appeared more intense.

3）The effect of ambient light on the contrast of AR virtual images is related to the transmission characteristics of the AR optical compositor optical combiner. If a filter is added, the contrast of the image can be improved. However, the external environment is also darkened, which affects the user's perception of the real scene. While such a visor is applied to increase contrast in a variety of ambient lighting conditions, it can be problematic in dimly lighting environments because of the reduced contrast of bright and dark objects in the physical environment. This means that viewers may not be able to distinguish between low-contrast real-world objects in the situation of wearing AR devices).

The results of the above studies indicate the need for further lighting design in the usage of AR devices and provide the guideline for refinement in the design of AR devices and the ambient light sensors to achieve better contrast in general lighting conditions.

4. Conclusions

In conclusion, ambient lighting can have a significant impact on the quality of AR images. To ensure that AR experiences are engaging and accurate, it is important for developers and device manufacturers to understand the applications their devices are targeting and consider these lighting factors when designing and optimizing AR software and hardware. In addition, the lighting design of the environment should also consider the characteristics of AR according to the actual purpose of use, to ensure that there is a suitable contrast.

OP14

INVESTIGATING THE IMPACT OF COMBINED DAYLIGHT AND ELECTRIC LIGHT ON HUMAN PERCEPTION OF INDOOR SPACES USING IMAGE PROCESSING AND VIRTUAL REALITY

Nikookar, N.[1], Omidfar-Sawyer, A.[1], Goel, M.[1], Rockcasle, S.[2]
[1] Carnegie Mellon University, Pittsburgh, PA, USA, [2] University of Oregon, Eugene, OR, USA
nnikooka@andrew.cmu.edu

Abstract

1. Motivation, specific objective

People spend more than 90% of their time indoors, and as such, improving the quality of light they are exposed to can significantly enhance their quality of life by creating visually appealing and comfortable environments. Numerous studies suggest that perceptions of a space vary depending on a number of lighting attributes present within a scene (brightness, contrast, distribution, colour, etc). Significant effort has been made across various fields to identify the spatial lighting conditions and attributes that impact human perception, although we lack studies that explore the impact of these conditions in tandem.

In recent years, computational methods have demonstrated potential in being able to analyse spatial light composition. By using image processing, multiple lighting attributes (scene contrast, luminance distribution, Correlated Colour Temperature (CCT), etc) can be quantified and measured. In the fields of architecture and lighting design, researchers have explored the link between human perception and the visual characteristics of light, such as local contrast and luminance distribution, by analysing scenes within the occupants' field of view. The algorithms developed as a result of these studies might not, however, be applicable to all spaces since they were conducted on daylit spaces in the absence of electric light.

Most studies investigating the impact of lighting conditions on the perceived quality of indoor spaces can be grouped into two categories: those conducted in laboratory settings and those conducted in virtual settings. In both settings, electric and natural light are often studied separately to ensure controlled research conditions. As a result, these setups may not accurately represent the lighting conditions of everyday space, as indoor lighting is a combination of daylight and electric light and changes dynamically throughout the day. Moreover, these experiments have been limited to the comparison of several metrics each and fail to capture the complex interactions and dynamic changes between different light sources. Therefore, investigating the combined impact of daylight and electric light on human perceptions of space in real-world settings is necessary to develop a more accurate understanding of the impact of light on visual interest and quality of life.

This project aims to investigate the impact of interior lighting (daylight and electric light) on human perceptions of space by evaluating several interior scenes that vary in sky condition, shading blinds position, the presence or absence of electric light and CCT. Image processing techniques are used to assess the perceptual performance of lighting in spaces that are lit with a combination of daylight and electric light. Impressions of these conditions are evaluated by analysing the captured scenes using various lighting metrics as well as subjectively in virtual reality (VR) environments.

2. Methods

As part of this study, two spaces at the Carnegie Mellon University campus in Pittsburgh were selected as case studies: a private office space and a conference room. Both spaces feature full-height windows and are naturally daylit. 360-degree high dynamic range (HDR) photography with a wide fisheye specification was used to recreate the spaces in a VR environment. The setup involved photographing each space under 12 different lighting conditions: one set of photographs was taken under sunny sky conditions, while the other set was taken under overcast sky conditions. For each sky condition, the spaces were

photographed with the lights turned on and off, and with the blinds both open and closed. Additionally, under each lighting condition where the lights were turned on, the spaces were photographed under two different types of colour temperature: warm (3000K) and cool (5000K).

Philips Hue White and Colour Ambiance A19 LED Smart Bulbs were used to create the different CCT levels. The resulting dataset provides a comprehensive analysis of the impact of lighting conditions and colour temperature on the visual and atmospheric qualities of the spaces.

In the first part of the paper, image processing is used to analyse the photographed scenes for lighting metrics that have shown to influence visual interest and impression of light, such as the Luminance Differences Index (LDI), Standard Deviation of Luminance, Dynamic Range, local contrast, and light CCT.

In the second part of the experiment, 60 participants (30 female and 30 male) between 18 to 40 years old were immersed in the created VR environment, where they were able to view the scenes from a fixed point in space. Participation was unpaid and voluntary and the participants were recruited by email or in-person. An Oculus Rift S headset with 2560 x 1440 resolution and refresh rate of 80 Hz was used in the experiment. Each experimental session took about 30 minutes. Participants were asked to subjectively rate the different scenes on seven-point semantic differential scales based on rating pairs of “calming vs exciting,” “like vs dislike,” “satisfying vs dissatisfying” and on four dimensions of "cosiness", "liveliness", "tenseness", and "impersonality” to quantify the perceived atmosphere.

3. Results

The results from the two parts are compared and analysed to find a model for predicting humans’ impression of indoor light by finding correlation between the investigated lighting metrics and the different dimensions of perceived atmosphere for each space. This research contributes to the field by identifying the correlation between different light measures and human impression of light, and identifying the best lighting solutions to improve visual interest.

4. Conclusions

Overall, this project aims to improve our understanding of the complex and dynamic nature of indoor lighting and its impact on human perception and experience of space. The findings can inform future research and design efforts to enhance lighting conditions and improve the quality of life for building occupants.

Session PA4-1
D3/D1/D6 - Integrative lighting 2
Tuesday, September 19, 12:30–14:05

OP4

A CONTINUOUS RATING EXPERIMENT TO TEST THE FEASIBILITY OF WORKING WITH HIGH-LUMINANCE MONITORS TO INCREASE LIGHT AT EYE LEVEL

Daneels, R.[1], Van de Perre, L.[1], Ryckaert, W.[1]
[1] KU Leuven, Ghent, BELGIUM
roel.daneels@kuleuven.be

Abstract

1. Motivation, specific objective

The upward trend of individuals spending more time indoors has resulted in a pronounced insufficiency of exposure to natural daylight. Especially during office hours, it is impractical for most people to go/work outside. Adequate indoor lighting should compensate for the lack of daylight by providing more light at eye level. Employing High Dynamic Range (HDR) displays with high-lumen output could be a way to accomplish this need for more light. Computer displays generally emit a slightly blue-tinted spectrum with a correlated colour temperature (CCT) of approximately 6500 K, making them well-suited to elicit intrinsically photosensitive retinal ganglion cells (ipRGCs) responses. Increasing display light output can generate a satisfactory level of melanopic equivalent daylight illuminance (melanopic EDI).

A possible remark is the feasibility of working with HDR displays emitting high luminance levels (e.g. above ~500 cd/m²). People will dislike working with a monitor if it is too bright for the environment. To address this issue, an experiment was developed to evaluate the reading comfort level under various monitor and ambient luminance levels. The experiment mainly focused on assessing reading comfort, as this is a task that is performed daily.

It was hypothesized that the reading comfort of high luminance monitor levels would increase with increasing ambient luminance levels.

2. Methods

A visual experiment was conducted using a repeated measures methodology in which observers evaluated reading comfort on a continuous rating scale. A 21.3-inch monitor was placed in an office-like room without any daylight. A lighting scene consisted of a fixed monitor luminance level and a fixed ambient luminance level. Four monitor luminance levels (120, 260, 453, and 700 cd/m²) and six ambient luminance levels (~0, 12, 34, 68, 113, and 170 cd/m²) resulted in 24 unique lighting scenes. The experiment comprised four sessions, each corresponding to a unique monitor setting.

Observers were instructed to read a text on the monitor for 10 seconds and then presented with a rating scale bar below the text. Subsequently, observers were instructed to evaluate the reading comfort of the lighting scene. Following the observers' response, the ambient luminance level was changed (the monitor luminance level was fixed). A break of at least 5 minutes was given after each experiment session (corresponding to one of the four unique monitor settings). This protocol was thus repeated four times.

Twenty observers, all native Dutch speakers, participated in the visual experiment. The text displayed on the monitor was in Czech, as Dutch-speaking observers could read the characters without comprehending the text, nullifying any influence the text could have on the decision-making process.

All lighting scenes were calibrated and the spectral irradiance was measured vertically at the eye level of the observer's position.

3. Results

The results show an apparent influence of ambient luminance level on the reading comfort score. As expected, an ambient luminance level of ~0 cd/m² (lights out) had the lowest reading comfort regardless of the monitor luminance level. Increasing the ambient luminance level improved the reading comfort score. However, this improvement reached a saturation point at an ambient luminance level of 68 cd/m². At this point, the ambient luminance level was considered to be sufficient to provide a comfortable reading environment.

Results indicated no influence of monitor luminance level on reading comfort score. For example, reading comfort for the highest monitor luminance level (700 cd/m²) already reached a saturation point at 68 cd/m², similar to the other monitor settings. The 700 cd/m² setting typically exhibits nearly six times the luminance of a typical monitor (~120 cd/m²). Therefore, it was hypothesized that an ambient luminance level of 170 cd/m² or higher would be necessary. However, increasing the ambient luminance level above 68 cd/m² did not further improve reading comfort. Contradicting the idea that high-luminance monitors would require a higher ambient luminance level towards obtaining similar reading comfort.

The measured spectral irradiance of each scene was used to calculate the melanopic EDI. According to the literature, adequate lighting should provide a minimum of 250 lux melanopic EDI during the day. This threshold was only reached for 7 of the 24 unique lighting scenes. For the two lowest monitor luminance levels, 250 lux melanopic EDI is only reached in combination with the highest ambient luminance level of 170 cd/m². For the two highest monitor luminance levels (453 and 700 cd/m²) this threshold was already reached at 113 and 68 cd/m² ambient luminance, respectively.

4. Conclusions

The experiment partially confirmed the hypothesis that increasing the ambient luminance level is necessary to increase reading comfort. However, given that the highest monitor luminance level is nearly six times the lowest luminance level, it is unexpected that the results indicate no influence of monitor luminance level on reading comfort score. In addition, around half of the observers indicated perceiving different reading comfort between sessions. Interestingly, for all monitor luminance levels, including the 700 cd/m² setting, a saturation point in reading comfort is reached at around 68 cd/m² of ambient luminance.

Given these results, an ambient luminance level of 68 cd/m² appears to provide the best reading comfort score for all monitor luminance levels. The combination of a monitor luminance level of 700 cd/m² with the ambient luminance level of 68 cd/m², resulted in a scene that reaches the 250 lux melanopic EDI. Based on the current results, using an HDR display with high-lumen output can be recommended. However, the current experiment might be insufficient to fully capture the true differences between monitor luminance levels. The rating scale experiment is prone to bias and during each experimental session, observers only evaluated one monitor luminance level. Therefore an additional visual experiment is planned, employing a paired comparison psychophysical procedure in which observers are presented with two lighting scenes and asked to select the scene with the higher reading comfort. Combining the results of these two experiments might provide a more accurate answer to the research question.

OP17

LIGHTING HYGIENE, MELANOPIC DAYLIGHT EFFICACY RATIOS AND ENERGY EFFICIENCY

Price, L.L.A.[1], Schlangen L. J. M.[2]
[1] UK Health Security Agency, Chilton Didcot, Oxfordshire, OX11 0RQ, UK, [2] Intelligent Lighting Institute, Eindhoven University of Technology, NETHERLANDS
Luke.Price@ukhsa.gov.uk

Abstract

1. Motivation, specific objective

The second Manchester Workshop published recommendations about minimum daytime and maximums for evening and night-time exposures to light in terms of vertical melanopic equivalent daylight illuminance (melanopic EDI). Lighting design and measurement must also consider surface illuminance and visual function; melanopic EDI at the eyes for non-visual function being a relatively new target that has not been widely incorporated into lighting guidance.

The spatial and spectral differences between visual and non-visual targets can be exploited by designers attempting to satisfy both needs. This paper considers the spectral aspects through the use of the melanopic daylight efficacy ratio (melanopic DER), which is the ratio of melanopic EDI to illuminance.

In circadian light hygiene regimes, the evening calls for a light with a low melanopic daylight efficacy ratio (melanopic DER) to assist designs that provide sufficient illuminance for visual function, whilst limiting the melanopic EDI. In the daytime, where electric lighting is needed, in contrast, a higher melanopic DER is desirable. It is a matter of social and economic importance that these two different spectral objectives may both strongly conflict with the use of luminous efficacy to determine how much net positive utility derives from each metered Joule of electrical energy, or potentially each tonne of CO2 produced.

The Manchester Workshop also identified that there were studies emerging showing visually matched or metameric LED spectra with different melanopic DER values. It is helpful in the present analysis that the LED lighting data that will be considered pre-dates the emergence of these newer LED spectral designs to target either higher or lower melanopic DER. The paper will use the unmodified LED spectral together with daylight spectra to discuss the appropriate range for lighting with of a given correlated colour temperature (CCT), to meet both visual and health purposes simultaneously – whether for daytime or evening and night-time.

This paper compares LED lighting and daylight, how the use of melanopic EDI inter-relates to the use of colour temperature for visual purposes, commenting on the prior use of CCT as a proxy for relative non-visual efficacy, and discussing the electrical energy implications.

2. Methods

Published traceable spectral data on LED lighting and daylight are reused in this analysis (with acknowledgement to previous contributions of colleagues), that uses the CIE S 026 Toolbox. Charts were produced using Excel, with non-linear axis replaced with data series. All equipment details have been previously described.

High resolution daylight spectra and hemispherical colour photographs were acquired in the horizontal plane every 300 seconds, at a UK site (51,57 N). Spectral data from two days with characteristic clear and cloudy conditions were selected.

Non-tuneable LED lighting products were selected in 2015, under collaborative guidance of a panel of lighting specialists from the Chartered Institution of Building Services Engineers (CIBSE). Three or more units were purchased of white LED lighting product with BC22 and

GU10 fittings, both being common in the UK, including all products available to a hypothetical Oxfordshire consumer through online and high-street retail channels. Smaller additional samples were taken from other fittings or channels, including office and street lighting, to include the full range of available CCTs; office and street lighting all had relatively high CCTs. High resolution LED spectra were measured in light and temperature-controlled laboratory conditions. Emissions were stabilized before acquisition. Measurement distances were 300 mm for domestic lighting and small office panels, and 500 mm for street lighting and large office panels. For dimmable products, only full measurements power are included, but the relative spectra did not change significantly on dimming.

3. Results

The CCT for daylight is matched by the LED lighting, whilst melanopic DERs for daylight from above 10 degrees solar elevation are not reproduced. Daylight melanopic DER values are continuous down to roughly 0.96 at double digit solar elevations on clear days, whereas the LED lighting has a spread of melanopic DER (min 0.32, max 0.79, median 0.41). Daylight CCT values are also continuous, down to roughly 5925 K at double digit solar elevations on clear days, whereas the LED lighting has a non-uniform spread of CCTs with a range of 2614 K to 6605 K. Cloudy conditions, lower elevations and other indirect vertical daylight aspects increase the lowest CCT and melanopic EDI further. Monotonic trends are evident between melanopic DER and CCT in both the two daylight series and the LED data, but at their intersection around 6500 K, the melanopic DER in daylight is uplifted by around 40% relative to the LEDs.

The paper explores these relationships graphically, reconsidering definitions of electrical energy efficiency. In addition, it discusses melanopic DER values that might be suited to lighting with a given CCT, based on a mini-review of melanopic DER engineering in metameric LED spectra in non-visual research.

4. Discussion and conclusions

A light hygiene regime, such as the one proposed by the Manchester Workshop for healthy day-active adults up to age 50, is known to be important for healthy sleep and circadian rhythm regulation (SCRR), as opposed to sleep and circadian rhythm disruption (SCRD), which is associated with multiple leading morbidities.

The range of melanopic DER achieved in non-visual response experiments using specifically engineered LED lighting is a factor of 2.5 to 3. Nature has determined that the maximum value of this factor is restricted by the interactions between the sensitivity ratios of melanopsin to the three cone-opsins over a range of wavelengths when creating metameric sources. Nevertheless, 250% is a significant degree of design freedom for spectral engineering in terms of how much visual light is delivered whilst keeping a non-visual light hygiene regime for supporting SCRR and minimizing SCRD. However, humans may be inadvertently introducing further restrictions, as energy efficiency calculations need to adjust towards favouring useful melanopic efficacy during the day, and penalizing unwanted melanopic efficacy during the evening and at night-time (or other periods of needful rest).

OP75

EFFECTS OF LIGHT ON ATTENTION OF FULLTIME DAYTIME WORKERS

Rolf, H.[1], Udovicic, L.[1], Völker, S.[2]
[1] Federal Institute for Occupational Safety and Health (BAuA), Dortmund, Germany,
[2] Technical University of Berlin (TUB), Berlin, Germany
hannah.rolf@campus.tu-berlin.de

Abstract

1. Motivation, specific objective

Since the discovery of the ipRGCs, research interest in non-image forming effects of light has grown enormously. In particular, for the impact on the human circadian system, a dependency of ipRGC-activation in terms of melanopic equivalent daylight illuminance (MEDI) could be shown. Insufficient MEDI levels during the day or levels that are too high at night result in phase shifting and eventual desynchronization. Apart from such circadian responses, also acute alerting effects of light have been investigated. These responses have been especially shown to exist during the night. Nowadays, more studies focus on alerting effects during daytime, since most people are exposed to natural or artificial light during the day, rather than the night. Comparability of these studies is impeded by a high variety in study designs, including different types of lighting, light levels, spectral compositions, exposure durations, or participant populations. Generally, some studies found alerting effects of light during the day, while others could not confirm such. However, there is a tendency towards an alerting effect of higher illuminances and blue-enriched light, pointing to the hypothesis, that an increase in MEDI might improve attention during the day. If light can improve attention during the day, this response may be used to support people at work who often are exposed to the lighting conditions at their workplace for several hours a day. Regarding exposure durations, it is striking that most studies so far have only considered exposures of up to two hours. Therefore, effects of exposure durations similar to those of fulltime workers at workplaces are poorly investigated. In addition, lighting scenes often included illuminances or spectra which did not comply with existing regulations for workplace lighting. The aim of the presented study is to investigate alerting effects of light on fulltime daytime workers. The resulting knowledge is essential in order to provide supportive lighting at workplaces in terms of non-image forming effects.

2. Methods

We executed a laboratory study in a within-subject design that included 42 participants. Participants were younger than 35, non-smoking, non-sleep disturbed and no extreme chronotypes. Three different lighting scenes, which fulfilled existing regulations for workplace lighting, were applied. In the first one (WL: warm low) horizontal illuminance at desk was set to 500 lx at a CCT of 2700 K. For the second (CL: cold low), illuminance was held constant, while the spectrum was changed. This resulted in a CCT of 5400 K. For the last (CB: cool bright), spectrum was not changed while the illuminance was increased to 1500 lx at desk level. The first scene provided a MEDI of 135 lx, which was increased by a factor of 2.1 to 258 lx in the second scene. For the cool bright scene, MEDI was increased by a factor of 2.8, resulting in a value of 807 lx.

Participants arrived in the laboratory on four session days. The cool bright scene was presented twice. The order of lighting scenes was randomized between participants. Attention was assessed several times during session days – six test phases and four working phases, which resulted in an overall exposure duration of 7.5 hours, were included. In test phases, attention was assessed via subjective scales as well as psychomotor task. We included the Karolinska-Sleepiness-Scale (KSS), the NASA-TLX, a visual analogue scale for mood and questionnaires about lighting and premises. Additionally, a short version of a psychomotor vigilance task (PVT), a combination of a Go-NoGo-Task and a 2Back-task, as well as a simple Go-NoGo-task was executed. Between test phases, participants completed work tasks. Two of them focused on motoric work, while the others simulated knowledge work. This design

ensured that attention had to be maintained over the full course of the day, similar to fulltime working days.

Results were analysed using linear mixed models. Covariables were chosen via forward selection based on AIC.

3. Results

Significant effects of the lighting scenes were found for some parameters, but not all. Participants responded significantly faster in the PVT under the warm lighting, compared to both cold lighting conditions. Lapses during PVT were significantly increased under the bright lighting. Additionally, participants responded to significantly more correct stimuli of the 2Back-task under warm lighting, compared to both other lighting scenes. Other parameters of psychomotor tasks did not show significant effects. The mood-scale, as well as most subscales of the NASA-TLX showed significant differences. In all of them, the warm lighting showed best results. This trend was also seen in the KSS although statistical significance was not reached.

The warm lighting was rated as significantly less exhausting and more comfortable than both cool lighting scenes.

4. Conclusions

In general, results of psychomotor tasks, as well as subjective ratings, were better under warm lighting. This contradicts the aforementioned hypothesis that an increase in MEDI would result in an improvement of attention during the day. However, since participants rated the cold lighting scenes as rather unpleasant and exhausting, it is possible that negative effects of an experienced discomfort may have counteracted positive effects of an increase in MEDI. When designing lighting scenes and laboratory rooms in future studies, the impact of lighting on comfort and mood should be particularly considered. Thereby, a broader knowledge can be generated in order to create a supportive working environment in terms of non-image forming effects but also well-being.

OP10

THE CONTRIBUTION OF IPRGC-RELATED MELANOPIC ILLUMINACE TO SPATIAL BRIGHTNESS IN INTERIOR SPACES

Hu, Z.[1], Li, J.[1], Zhang, M.[1], **Dai, Q** [1,]
[1] Institute of Future Lighting, Academy for Engineering & Technology, Fudan University, Shanghai, CHINA
qidai@fudan.edu.cn

Abstract

1. Motivation, specific objective

Visual comfort is an important part of lighting quality in indoor environment. Spatial brightness, an essential factor that affects visual comfort, is influenced by spectral power distributions (SPDs) of lighting that cannot be predicted by the photopic luminous efficiency function $V(\lambda)$. The fundamental mechanism of spectral sensitivity for spatial brightness remains unclear. Previous studies have suggested that the short-wavelength portion of spectral sensitivity for spatial brightness perception might be partially explained by a contribution from intrinsically photosensitive retinal ganglion cells (ipRGC). However, these studies have not clearly confirmed the actual impact of ipRGC on spatial brightness by excluding the interference of potential contribution from other photoreceptors such as S-cone.

This current work is aimed to investigate the contribution of ipRGC-related melanopic illuminance on spatial brightness perception and its relative effectiveness at various photopic illuminance levels. To obtain a clear conclusion, the impact of other spectral factors, especially the photopic illuminance and cyanopic illuminance, are carefully excluded by keeping them at a fixed level among different test SPDs. The results concluded that ipRGC-related melanopic illuminance had a positive impact on spatial brightness when the lighting intensity is below 225 lx. Such a result could provide valuable insights toward the establishment of a comprehensive spectral sensitivity model for spatial brightness of interior spaces.

2. Methods

The experiments of spatial brightness comparisons were performed in a windowless room equipped with linear wall-washing luminaires located around the ceiling that delivered indirect light to observers. Each luminaire was spectrum- and intensity- tunable with nine independent channels containing LED sources with different spectrum, which allowed laboratory personnel to individually control the melanopic illuminance at the eye-level, while maintaining other lighting parameters, such as photopic illuminance, cyanopic illuminance, and color-rendering parameters, at a fixed level. Specifically, five test SPDs were designed to achieve identical x-y chromaticity coordinate (0.3805, 0.3768), which corresponds to a CCT of 4000 K, a fixed photopic illuminance (150.0 ± 0.5 lx), cyanopic illuminance (87.4 ± 0.5), and R_g (≈100), as well as reasonably good R_f (>70) that meet general-lighting requirements, but significantly different melanopic illuminance. The measured values of melanopic illuminance for the five test SPDs were 103.0, 116.4, 129. 6, 145.7 and 158.1, respectively. Among them, the test SPD with the medium level of melanopic illuminance (129.6) was selected as the reference SPD (named as SPD-1) and the other four were named as SPD-2, SPD-3, SPD-4 and SPD-5, respectively, according to their measured values of melanopic illuminance from low to high.

A total of 44 pre-qualified subjects participated in the experiment. Spatial brightness evaluations were conducted by comparing various test lighting scenes with a fixed reference lighting scene, which delivered a fixed spectrum of SPD-1 at corneal illuminance of 150 lx. Test lighting scenes delivered test SPDs, each tuned to 11 different levels of corneal illuminance ranging from 75 to 225 lx with an interval of 15 lx, to subjects' eye level. Subjects were asked to make a forced choice between the test and reference scenes in terms of which scene has a higher level of spatial brightness. For each test SPD, the percentage of subjects

who reported the test scene being brighter (*P*) versus corneal illuminance of the test scene were obtained. The corneal illuminance needed for each test scene to match the spatial brightness perception of the reference scene was defined as the matched illuminance, at which *P* = 50%. It could be quantitatively calculated by fitting the data with a Logistic function and finding the point with *P* = 50%. The corresponding matched illuminances of various test SPDs were compared to investigate the impact of ipRGC-related melanopic illuminance on spatial brightness perception.

3. Results

First, a null-condition trial with SPD-1 as both reference and test scenes was conducted to confirm the removal of systematic biases and verify our method. Then four comparison trials were conducted between the fixed reference scene with SPD-1 and four test scenes with SPDs-2~5. For each test SPD, the corresponding illuminance needed to match the spatial brightness of the reference scene were 149.4 lx (95% Confidence Interval (CI): 147.8 – 151.1 lx), 152.5 lx (95% CI: 151.0 – 154.0 lx), 152.4 lx (95% CI: 151.3 – 152.9 lx), 148.2 lx (95% CI: 146.7 – 149.8 lx) and 146.1 lx (95% CI: 144.9 – 147.3 lx) for SPD-1, SPD-2, SPD-3, SPD-4 and SPD-5, respectively. These results demonstrated that ipRGC makes a positive contribution to spatial brightness: the increase of ipRGC-related melanopic illuminance leads to a clear decrease in matched illuminance for test SPDs.

Next, an additional comparison trial was conducted to directly compare SPD-2 and SPD-5, which had the greatest difference in melanopic illuminance at the same photopic and cyanopic illuminance. By using SPD-2 at 150 lx as the new reference scene and SPD-5 from 75 to 225 lx as the test scenes, the corresponding illuminance required for SPD-5 to match the spatial brightness of SPD-2 at 150 lx was 142.2 lx (95% CI: 140.3 – 144.0 lx), which further confirmed the positive impact of melanopic illuminance on spatial brightness perception.

Finally, a one-by-one comparison trial was performed between SPD-2 and SPD-5 at various photopic illuminance levels ranging from 0 to 300 lx. The results showed that more than 50% of subjects reported SPD-5 had a higher level of spatial brightness when the corneal illuminance was below 225 lx. A clear positive effect of ipRGC on spatial brightness existed particularly in the range of 75 to 150 lx, which is the range typically adopted in interior lighting. At an illuminance of 75 lx, 62.5% of participants (95%CI: 52.2% – 72.8%) reported SPD-5 as having higher spatial brightness than SPD-2.

4. Conclusions

In this work, experiments were performed for spatial brightness comparisons between lighting scenes with different SPDs. These SPDs were specifically designed to have significant differences only in ipRGC-related melanopic illuminance while other factors were kept at a fixed level. The results provided clear evidence that ipRGC, which was traditionally considered as a non-visual photoreceptor, has a clear positive contribution to spatial brightness perception at photopic corneal illuminance below 225 lx. The outcome of this work could provide important insights towards understanding the fundamental mechanism behind the spectral sensitivity for spatial brightness perception and final establishment of a spectral sensitivity model. Such a model is crucial to the effort of improving energy efficiency while maintaining a desirable spatial brightness in interior lighting.

OP42

VARIATION IN NON-IMAGE FORMING EFFECTS OF LIGHT AT THE WORKPLACE: A PILOT STUDY IN SWISS OPEN-PLAN OFFICES

Karmann, C.[1,2], Pierson, C.[1,3], Danell, M.[1], Wienold, J.[1], Barthelemes V.[4], Khovaly, D.[4], Andersen, M.[1]
[1]Laboratory of Integrated Performance in Design (LIPID), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, SWITZERLAND, [2]Laboratory of Architecture and Intelligent Living (AIL), Karlsruhe Institute of Technology (KIT), Karlsruhe, GERMANY, [3]School of Civil and Construction Engineering, Oregon State University (OSU), Corvallis, OR, USA, [4]Integrated Comfort Engineering (ICE), École Polytechnique Fédérale de Lausanne (EPFL), Fribourg, SWITZERLAND

caroline.karmann@kit.edu

Abstract

1. Motivation, specific objective

Health requirements for lighting in buildings are becoming increasingly important in building standards. Models to determine the light exposure needed for proper circadian entrainment and alertness at the desired time are still in their early stages of development. At the same time, there is a lack of concrete data on the lighting conditions that actually prevail in our workplaces, in terms of their seasonal variation, their spectral characteristics, the influence of orientation or the chosen electric lighting strategy, and how they might impact occupants' well-being. The objective of this study is to start addressing this gap by offering insights into what lighting environments typical Swiss open-plan offices provide to their occupants regarding non-image forming (NIF) effects of light.

2. Methods

2.1. Case-study spaces

We conducted continuous measurements of spectral irradiance and photopic illuminance over several periods of two weeks in two open-plan offices (referred to as A and B) in Switzerland. Office A is on the second floor of a five-story building in Lausanne completed in 2011. It has a dominant Northern exposure as well as narrower façades towards the East and West. Shading is provided by Venetian blinds which are regulated automatically based on solar irradiance and wind speed, but can be overridden manually. Office B is on the fifth floor of a six-story office building in Geneva completed in the 80s with tenant-specific renovations. It shows dominant exposures to the South-East, South and South-West. Shading is provided by manually controlled Venetian blinds. Both offices have similar window-to-wall ratios and use freestanding luminaires that automatically turn on in response to illuminance and motion sensors signals as their primary lighting strategy in the office areas.

2.2. Data collection

The spaces were studied during measurement campaigns occurring in different seasons of 2019 and 2020. Each campaign lasted 14 consecutive days, and we only considered the hours between 7am and 6pm of weekdays in our analyses. We performed photopic illuminance and spectral irradiance measurements for each building and orientation. Measurements were taken horizontally from the occupants' desks. Up to 15 illuminance sensors (Delta Ohm HD2021 TBA connected to an Onset HOBO) and 4 spectral sensors (nanoLambda Korea NSP32m sensor head) were used. For the spectral irradiance measurements, we positioned one sensor nearby each façade, right next to an illuminance sensor. The energy consumption of the freestanding luminaires was used to inform when electric lighting was on. Objective measurements were completed with point-in-time occupant comfort surveys.

2.3. Data analysis methods

The analysis methods primarily rely on descriptive statistics. The metrics reported include photopic illuminance and melanopic-equivalent daylight illuminance (melanopic-EDI) as well as the cumulative non-visual direct response (nvR_D), used as a relative measure of alertness.

3. Results

3.1. Variations in Melanopic EDI

Impact of buildings and seasons: In office B, the average desk-level photopic illuminance was of 228 lux in Fall, 215 lux in Winter and 517 lux in Summer, and the melanopic-EDI was of 182 lux, 169 lux, and 466 lux for the respective seasons. By contrast, the average desk-level photopic illuminance and melanopic-EDI in office A were about three times higher in Fall and Winter. Our hypothesis is a lack of usage of the manually operable blinds in office B, which remained closed or partially closed for long periods of time, even when light levels were low and when the shading was not required for glare protection. The usage of automated blinds in office A could be a more suitable option to optimize daylight penetration.

Impact of orientation: Comparing East and West orientations for office A – and South-East and South-West for office B – we observed, as expected, that the East/South-East orientation will offer higher light levels in the morning on average, while the West/South-West will in the afternoon. Since for circadian entrainment, exposure to bright light is recommended especially in the morning, an Eastern orientation should be preferred when choice is given.

3.2. Impact on alertness

Cumulative direct response: Based on the recommended 4.2 threshold on the nvR_D scale for vertical measurements, we can compare office A to office B in terms of their potential to meet minimal cumulative light exposure requirements based on the horizontal measurements proxy we have available. The analysis shows that office A performs better than office B in that regard, with higher cumulative non-visual direct response for all orientations, while office B also suffer from a strong dependency on orientation when it comes to expected nvR_D-induced effects of light. More significant differences in light-induced alertness levels would thus be expected in office B between occupants depending on orientation.

3.3. Subjective results

While the recorded photopic illuminance levels were higher in office A, with a greater frequency of occurrence above the standard threshold (> 500 lux), we found that occupants reported more discomfort than in office B. Blind control in office B allowed the occupants to adapt the conditions to their personal preferences without being disturbed by automated control, which does not necessarily match requirements for “healthy” lighting but brings a sense of forgiveness when the conditions are not ideal.

4. Conclusions

We conducted on-site continuous measurements of spectral irradiance and photopic illuminance in two offices in Switzerland. The offices showed differences in exterior blind controls, which we identified as the key contributor for the differences in measured melanopic-EDI and in predicted non-visual direct responses (alertness). Office B has orientations potentially more conducive to higher light levels and appropriate non-image forming responses of the occupants, yet we observed higher photopic and melanopic equivalent illuminance in office A. This observation suggests that the blinds were kept closed for a longer time in office B. Automated blinds with manual override appeared as a more suitable option to optimize daylight penetration and NIF effects of light, even though it can negatively impact occupant comfort. To our knowledge, this is the first field study involving continuous measurements of spectral irradiance in offices.

Session PA4-2
D4 - Sustainability 2

Tuesday, September 19, 12:30–14:05

4-MONTHS FOLLOW-UP OF THE PERFORMANCE OF LUMINESCENT ROAD MARKINGS

VILLA, C., MARQUET, P.L., BREMOND, R., SAINT-JACQUES, E.
Université Gustave Eiffel, COSYS, PICS-L, F-77454 Marne-la-Vallée Cedex 2, FRANCE
celine.villa@univ-eiffel.fr

Abstract

1. Motivation, specific objective

In response to public lighting extinction, municipalities invest in innovative markings products. Especially, luminescent road markings are increasingly widespread for pedestrian and bicycle paths in order to improve visual guidance in unlit areas during nighttime. However, the photometric performance of these products over time is arguably not known. A light is emitted from the markings after absorption of photons from sunlight, with a delay from a few nanoseconds to several hours. The intensity of this emission depends on the quantity and on the spectrum of the light previously absorbed, and gradually decreases during the night. Therefore, the luminance of luminescent road markings corresponds to the addition of the light emission and of the light reflection and varies during the night. It also varies from one night to another depending on weather conditions, light pollution, presence of the moon, etc.

To be applied on the road, luminescent markings must ensure performance at least equivalent to traditional markings. Previous laboratory measurements show that the gain of luminescent road markings in unlit areas could vary from a few minutes to a few hours, depending on the nighttime illumination.

This paper proposes a longitudinal follow-up of four months of luminescent road markings. A method was developed to quantify the performance over time depending on the external conditions (lighting, temperature, rain). We study the variability of this performance and try to identify the main factors influencing it.

2. Methods

A low-luminance ILMD was developed and calibrated in our lab based on a front-illuminated cooled sCMOS camera fitted with a 2048×2040 resolution. The exposure time could vary from 13 µs to 10 s, enabling to capture High Dynamic Range images from three exposure times during daytime and nighttime. The camera placed in a waterproof case and fitted with a water cooling system was installed on the roof of the university. Green luminescent paint and a traditional white marking paint were applied on asphalt plates with a road marking machine to obtain two samples of each type. Couples of luminescent and traditional samples were placed in two different spots with an observation angle of 10° from the camera.

The measurements were conducted from 11/02/2022 to 14/05/2022, from 2 hours before the civil twilight to the sunrise. Luminance images were measured every five minutes. A Region of Interest (ROI) was defined on each sample. The mean luminance of each ROI was recorded over time, along with the ambient temperature and cumulated rain collected from the university weather station. The horizontal illuminance on the samples was estimated over time from the luminance of the traditional marking samples during dry weather days.

To assess the benefit of luminescent road marking, we have compared their performance with that of the traditional road marking. The ratio of the luminance of the luminescent sample over the luminance of the traditional one was computed for each couple of samples. A preliminary analysis was carried out in order to remove inconsistent data (camera noise, missing data, local shadow, etc).

A performance indicator was defined as the time during which the ratio is higher than 1, *i.e.* the luminance of the luminescent road marking is higher than the one of the traditional road marking, from 30 minutes before the civil twilight to 30 minutes before the sunrise.

A descriptive analysis was first conducted based on this performance indicator. Then, a correlation analysis explored to what extend the ambient temperature, the illuminance and the moon influence the performance.

3. Results

77 days, including 17 rainy days, were analysed. A large variability of the performance of the luminescent samples was observed from one night to another. The performance varies from 0 to eight hours depending on the night. Although the performance is most often less than 3h (median: 2h40), it regularly reaches durations above 4h. In dry weather, the mean performance is around four hours. In wet weather (rain between two hours before and after the civil twilight), the mean performance is around 1h.

During the nights with clear sky, dry weather and no moon, theoretical decay curves (as measured in the laboratory) are observed and the performance is found above four hours. The curves are noisier during cloudy days. In presence of the moon at dusk, the performance is reduced.

Pearson correlation tests have been conducted between the performance indicator and various variables related to the horizontal illuminance during twilight and during night-time, and to the ambient temperature. The correlation analysis confirms that the horizontal illuminance during twilight and during the beginning of the night impacts the performance of the luminescent paint. No correlation with the temperature was found, but during the four months of measurement, the temperature was in average between 8° and 15°C at twilight.

A model of the evolution of horizontal illuminance, from one hour before civil twilight to two hours after, is proposed with four parameters. A formula which predicts the performance as a function of two of the model parameters was derived.

4. Conclusions

The outdoor measurements of luminescent road marking samples confirm previous findings obtained in laboratory. In unlit areas, such as bicycle paths, it seems that a gain can be obtained compared to traditional markings during the few minutes to the first few hours of the night. Indeed, the performance largely varies from one night to another depending on weather conditions (rain, clear/overcast sky, light pollution), the presence of the moon, and the horizontal illuminance during twilight and during the first hours of the night.

A performance indicator is proposed for luminescent road markings. A method to predict the distribution of this performance during a long period (several months) was developed. It is based on the modelisation of the horizontal illuminance evolution before and after twilight. In future work, such method will be improved and applied on data collected over one year, in order to estimate the performance distribution based on the distribution of external conditions and propose some guidelines to assess and regulate the performance of such innovative products.

OP34

A FIRST STEP IN PERFORMANCE ASSESSMENT OF A GRAZING LIGHTING SYSTEM FOR MOTORWAYS: A PRACTICAL CASE STUDY CONSIDERING FOG AS THE MAIN INFLUENCE QUANTITY

Angrisani, L.[1], Bonini, G.[2], De Benedetto, E.[1], Rossi, G.[3]
[1] University of Naples Federico II, Naples, ITALY, [2] Movyon S.p.A., Florence, ITALY, [3] CIE Division 4 member, Turin, ITALY
i1rsv.att@gmail.com

Abstract

1. Motivation

Road lighting has the main task of allowing traffic, even at night, with acceptable safety conditions. Related requirements are a set of rules which, over the years, have been updated based on experience, visibility research, technological evolution and needs imposed by the context.
In recent years, grazing lighting systems have anticipated great potential for lighting motorways. Although in the literature several studies highlight the technical advantages of grazing lighting systems compared to traditional systems, the main problem concerns the correct sizing of the system. As a matter of facts, design, management, and maintenance of grazing lighting systems present some technical difficulties essentially due to the small number of installations and the lack of specific normative indications. Indeed, the current requirements are all based on experimental assessments and experience on traditional lighting installations. For example, the reduced luminance coefficient values considered in national standards and in CIE technical reports are of little help as the range of the angular parameters they consider is low compared to the actual needs. Worsening the matter these values were obtained from investigations conducted in the 60s-70s of the last century with asphalts that were considerably different from the current ones and they do not consider draining ones. The recent activities in CIE TC 4-50 and in the European research programme "Surface" mitigate this situation, but there is an evident lack of reflection data from the draining asphalt, data necessary for a correct design of the system and the choice luminaire characteristics for optimizing lighting and energy performance.

The present study carries out adequate analyses to draw up design and maintenance guidelines for grazing lighting systems. These guidelines could represent a useful reference at national and international standardization level for including, within standards, specific requirements for grazing lighting systems. The aim is to reach solid design basis for grazing lighting systems considering the current standard requirements and possible criticalities in calculations and in installation working conditions.

To achieve these goals, the following experimental and/or theoretical evaluations are foreseen:

- Experimental evaluation of the behaviour of the grazing lighting system in case of fog.
- Comparison simulations of energy performance and visibility of objects (FVO in the Italian standard) between grazing lighting systems and traditional type systems with the same lighting class and size of the illuminated carriageway.
- Experimental evaluation of the visibility of objects, in real field situations.
- Evaluation of the criticality in the transition from street lighting with grazing lighting to that in the tunnel with a traditional system and vice versa, in the case of one-way tunnels and in the case of one-way streets.
- Simulation of lighting on license plates and assessment of possible glare conditions towards other road users.
- Field measurement of the reflection characteristics of various types of surfaces and in various climatic and aging conditions.

- Comparison of the level of upward dispersion of the luminous flux (light pollution) between grazing lighting systems and traditional-type systems that meet the mandatory requirements of Italian regional laws.
- Comparison of the levels and conditions of lighting and glare of the pilot lighting installation or pilot lighting installation built with respect to design expectations.

In this abstract, we present the preliminary results obtained in relation to the presence of fog.

Fog could represent an advantageous situation for grazing lighting systems compared to traditional ones, considering the visibility of the road and any objects on the roadway. The investigation is carried out by designing and implementing a dedicated setup able to reproduce visibility conditions in a foggy environment.

2. Methods

Although there are models that describe the diffusion of light in fog, some years ago the CIE TC4-19 technical committee was dismissed without producing a technical report. Due to the difficulty of applying these models in this case, the investigation is carried out by designing and implementing a dedicated setup able to reproduce natural fog and visibility conditions.

The experimental investigation is carried out in a climatic chamber of adequate dimensions allowing to build a small system inside and to enter by a car to simulate the presence of traffic. The obtainable fog has the typical characteristics of natural fog, and the investigation can be performed through measurements of the luminance, reduction of contrast of objects and of a target panel texture placed in defined positions and of light diffusion.

In the cold chamber, with black walls to reduce the effect of inter-reflections, a testing zone is considered simulating a two-line carriageway. A target of 2 m x 3.25 m with different contrast areas is used to obtained quantitative data about the reduction of perceived contrast due to the atmospheric luminance created by diffusion of light in different directions of view.

Measurements are carried out considering different layouts with a typical luminaire for traditional systems and one or two luminaires for grazing lighting systems, able to produce symmetrical, counter-beam and pro-bream lighting.

These luminaires are also equipped with an orange light source for signalling purpose.

3. Results

Considering a grazing lighting system, compared to a traditional system, the following conditions materialize:

- lighting is greater on the roadside, providing the driver with greater optical guidance on the limits and direction of the lane;
- the light emitted is concentrated at heights lower than those of the driver, thus reducing the effect of diffusion towards the driver;
- both backscattering and forward scattering of light are concentrated in directions transverse to the carriageway.

4. Conclusions

The obtained results will allow the designer to evaluate the performance of the system in the presence of fog and, in the case of installations in particularly foggy areas, to evaluate installation conditions (orientation and spacing) of the lighting system that optimize safety with respect to energy savings. For grazing lighting systems in the presence of fog, a pro-beam solution greatly reduces the effect of lighting diffusion towards the driver, and this suggests different rules in the luminous intensity distribution of luminaires according to normal situations (energy saving) and adverse climatic conditions (reduction of the fraction of light diffusion towards the driver).

OP44

TOWARDS PUBLIC LED LIGHTING WITH MINIMAL IMPACT ON INSECT MOVEMENT

De Causmaecker, L.[1], Mentens, A.[1], Vanschoenwinkel, B.[2], Moortgat, R.[2], Jacobs, V.A.[1,3]
[1] Mobility, Logistics & Automotive Technology Research Centre (MOBI), Dep. of Electrical and Energy Engineering (ETEC), Vrije Universiteit Brussel, Brussels, BELGIUM, [2] Community Ecology Laboratory, Department of Biology, Vrije Universiteit Brussel, Brussels, BELGIUM, [3] Rectorate, Vrije Universiteit Brussel, Brussels, BELGIUM
Valery.Ann.Jacobs@vub.be

Abstract

1. Motivation, specific objective

The rise of LED technology in public lighting has had a positive impact on society in terms of safer traffic conditions. Its low cost and energy consumption generally lower the need and desire for costly lenses and specialized fixtures. As a result, light pollution is rising along with the application of LED technology in public lighting. Due to the increasing concern of ecologists with the rapid decline of insects in Western Europe, the impact of artificial light at night (ALAN) on fauna has been subject to several recent studies.

ALAN appears to affect insects e.g. by attraction or repulsion, interference with pollination, feeding, chemical communication and mating behaviour. Differences in spectral power distribution and luminous flux have so far shown to be the most influential characteristics on so-called insect phototaxis: a movement-based response to the stimulus of light. The objective of this study is to get an understanding of the relationship between the Correlated Colour Temperature (CCT) and temporal light modulation of artificial light at night (ALAN) and correlating species-specified insect behaviour.

Previously our team investigated the effects of temporal light modulation on insect attraction/ repulsion. Descriptive statistics on our preliminary results showed that insect attraction was higher for light sources with no light modulation, in contrast with modulation under their currently perceived flicker fusion threshold. By improving our method and measuring period during this study, clearer results on the correlation might be possible. Second, this study focuses on CCT. Results of other studies showed that, when only blue light was used (peak at 465 nm), insect attraction was higher. Public lighting often has CCTs of 4000K or higher, due to increased brightness perception and the improved colour rendering index. By combining temporal light modulation and CCT in a high-quality study spanning 4 months, we hope to gather conclusions on the least attractive nor repulsive LED lighting settings.

Although the applications of this research subject are widespread (e.g. biodiversity monitoring, insect repulsion methods), our findings will be aimed towards innovation regarding the issue of declining urban insect populations due to ALAN and thus contributing to preserving local ecosystems and indirectly human well-being. While comparable studies show results that are confusing at best, this study is part of a multi-year research effort to get a thorough understanding of the complex relationship between insects and ALAN. Studies on the impact of ALAN on bats have already had an impact on society: the resulting expertise is being used by innovative cities around the globe to create more fauna friendly habitats. This shows that with the right research and resources, effective change is possible.

2. Methods

The sensors used for this research consist of an LED light source, a microcontroller and camera. The light source attracts nocturnal insects. A picture of the light source is taken at

timed intervals (every 10 seconds). Following a measurement period of 10 minutes is a minute of darkness to allow insects to spread out. The light source consists of a diffuse matrix of both warm (3000 K) and cold (6500 K) LEDs. An automated script drives the light source with the desired CCT and correlating luminous flux, while a specially designed driver controls the temporal light modulation. An image processing script pre-processes the pictures for the image recognition pipeline, on which Deep Learning is applied to identify the group species of the insects. Moreover, it is possible to count them and measure their dimensions and biomass. Lighting conditions (CCT, temporal light modulation) and environmental conditions (temperature, humidity, wind speed, illuminance of the sky) are collected in a database, corresponding with the identified species.

Four sensors are placed in a 2 ha woodland near Houffalize in the Ardennes, Belgium. A minimal distance of 30 m is kept between the sensors: a minimal distance to ensure statistical independence between the set-ups. The sensors measure during the same periods, ruling out variations in temperature, humidity, moon cycle, general weather patterns and species-specific periods of activity. Different CCTs ranging from 2700K to 6500K (2700, 3500, 4100, 6500 or evenly spaced) will be tested. Light modulation values will be determined during the preliminary testing of this study. Colour Rendering Index will always be above 80 so that the tested lights are still compliant to standards and norms EN12464-1 and EN13201 Road lighting.

By varying CCT and temporal light modulation in different case set-ups, it might become possible to lower insect phototaxis and thus the influence of ALAN on insect functioning. Relevant data collection is assured by measuring four months (spring and summer) while obtaining environmental factors that could possibly influence insect behaviour. The sensors will be able to collect data for unlimited periods without human intervention.

3. Results

At the time of writing, insect movement is minimal due to winter conditions. Preliminary measurements will start mid-March. Qualifying measurements will take place from April 1st until July 31st. We expect the first results to emerge by mid-June, in due time to present them at the conference.

4. Conclusions

As the first results of the study will only be processed by mid-June, it is too early to draw any conclusions from the measurements at any time prior. It is expected that higher CCTs will have a larger impact on insect phototaxis and thus a larger negative effect on the functioning of nocturnal insects. This due to the higher blue spectral components of high CCTs. Measuring CCTs and horizontal illuminance, and noting luminaire specific luminous flux (found in the datasheet) of common public LED lighting in and around our campus would allow to compare our results with current lighting solutions and help consultation on lighting infrastructure.

OP55

WHAT TO REPORT IN STUDIES OF ANTHROPOGENIC LIGHT AND LIGHT POLLUTION

Jägerbrand, A.K.[1], Durmus, D.[2], Nilsson Tengelin, M.[3]
[1]Department of Electronics, Mathematics and Natural Sciences, Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, SWEDEN, [2]Department of Architectural Engineering, Pennsylvania State University, USA, [3]Department of Measurement Science and Technology, RISE Research Institutes of Sweden, Borås, SWEDEN,

annika.jagerbrand@hig.se

Abstract

1. Motivation, specific objective

Light at night (LAN) is beneficial for use of outdoor environments during darkness for humans but may also have harmful side-effects, which are commonly referred to as light pollution. Light pollution is defined as the sum total of all adverse effects of artificial (electric or anthropogenic) light and is divided into three key areas: atmospheric and astronomic light pollution, ecological light pollution, and effects on humans and human health. During the last decade, there has been a dramatic increase in scientific publications and knowledge gathering of LAN's environmental consequences.

Numerous scientific studies have alarmingly claimed that anthropogenic outdoor light causes adverse and even mortal effects on several species, including humans. Studies also claim that LAN causes a reduction in biodiversity, for example, in insects which are critical for life on earth. However, assessing the validity and reliability of many light pollution studies is difficult since light exposure is not included or vaguely reported. In addition to the lack of reporting of experimental details, it is common that confounding factors are not reported or acknowledged. Measurement methods are highly variable, which prevents comparing results from different studies.

Studies may exaggerate the effects of anthropogenic light, for example, when ignoring significant confounding factors, or underestimate effects, for example, when reporting light conditions from locations or angles that are not correlated with light exposure. This results in challenges in developing light pollution mitigation measures, standards and recommendations to accomplish progress towards sustainable development.

Therefore, this study aims to provide preliminary guidance for the reporting in investigations of effects of anthropogenic light and light pollution which can be used for input to future recommendations and reports by the Commission Internationale de l´Eclairage (CIE) (e.g., CIE TC 4-61 and CIE TC 2-95).

2. Methods

Several hundreds of scientific publications in the three key areas have been read and extracted for systematic reviews on light pollution. Literature searches were done systematically, covering scholarly peer-review articles published until 2022. The validity and reliability of the studies have been evaluated using inclusion and exclusion criteria. Results were assessed, and best practices for reporting experimental protocol (location details, stimuli, measurement, dependent variables, statistical analysis) were collated following templates from similar CIE guidance documents.

3. Results

3.1 Project details

For human health studies, the population is often well described in descriptive, general terms (e.g., number of participants, age, sex), while visual characteristics and reporting of other factors relating to the scope of focus (e.g., light history) can be improved. For studies of wildlife species, descriptive details on population numbers are often given for controlled or

laboratory experiments. In field observations, the population inhabiting an area is often unknown, and observations are sometimes restricted to those attracted to or affected by the light. Also, the study organisms' visual characteristics (e.g., visual system sensitivities) should be reported.

For human health studies based on satellite data, details, such as date and time and geographical location, are reported but the characteristics in space (light exposure of humans) are often unknown and seldom reported. Unfortunately, lighting providing visibility for humans or organisms is usually not described in satellite studies. There is often a mismatch in the description of the light conditions of the geographical area and the participants viewpoint of the same area. In ecology, project details on the context and characteristics depend on the type of experiment or observations, but the organism's viewpoint is often neglected. Several confounding factors can impact the effects of anthropogenic light in the outdoor environment (e.g., natural light, urbanisation, and temperature conditions), and they should be measured and analysed.

3.2 Stimulus (independent and control variables)

Lighting is the primary independent variable in light pollution and should be carefully characterised whether the study is lab, observational (field), or longitudinal (satellite-based). Studies should report photometric and radiometric quantities, measurement location, exposure duration, spectral power distribution of the light source(s), temporal characteristics of the light source(s), and measurement equipment.

Measurement data should be made publicly available whenever possible to allow replication of the studies or meta-analysis. Measurements should be relevant for the light exposure of the study species in the specific study environment. In addition, researchers should report or, at the minimum, acknowledge potential confounding factors, such as temperature, humidity, and nutrition in lab studies, weight, education, socioeconomic status, smoking, alcohol use, urbanisation, menopausal status, diet, and physical activity in longitudinal studies.

3.3 Measure (dependent variables)

The dependent variable is highly variable since studies are done in many disciplines, species, and environments. Lab studies focused on the health of model animals can report changes in behavioural (e.g., sleep, activity), physical (e.g., body mass index, obesity), and physiological (melatonin, gene expression, cancer growth) parameters. For satellite-based or aerial-based studies, mismatches in temporal and spatial scales between anthropogenic light assessments and responses are not uncommon. In ecology, many studies use control-impact (i.e., dark/lit) experimental design rather than the superior before-after-control-impact (BACI) design or several light exposure levels, resulting in difficulties in identifying responses to the light conditions *per se*.

3.4 Statistical analysis

At the very minimum, studies should report descriptive and inferential statistics. Researchers with clear hypotheses (e.g., light pollution harms animals) should use hypothesis testing and avoid malpractices, such as p-hacking. Researchers should also check all the assumptions (normality, equal variance, independence) before using parametric tests. Significant results should be accompanied by effect size and direction.

4. Conclusions

There is an urgent need to develop recommendations for documentation and reporting in light pollution research. Although research is growing, the quality of the research should expand with the quantity. Studies should detail experimental protocols to enable reliable and valid scientific results. Researchers should document project details, independent, control, dependent, and confounding factors, and conduct appropriate statistical analysis. Interdisciplinary collaboration between lighting and ecology researchers and other relevant fields can significantly improve the quality of outcomes and is therefore highly recommended.

OP70

BILLBOARD LIGHTING SYSTEMS MODELING FROM THE POINT OF VIEW OF ITS RADIATION INTO UPPER HEMISPHERE

Novak, T.[1], Vavra, L.[1], Valicek, P.[1], Gono, R.[1]
[1] VSB - Technical University of Ostrava, Ostrava, CZECH REPUBLIC
tomas.novak1@vsb.cz

1. Motivation, specific objective

The radiation of various light sources into the upper hemisphere is increasingly attracting the attention of experts with the aim of minimizing this radiation as much as possible. From the perspective of minimizing this radiation the vertical light sources represent very significant source of radiation. These can range from the smallest, such as windows, to the largest, such as the illuminated facades of skyscrapers. Illuminated billboards fall somewhere in between these vertical light sources in terms of their size, average luminance, and number. Since these billboards are often found not in illuminated city or town centres, but in dark natural areas near roads, they are often the centre of attention. However, they are not considered systematically, but only as individual potentially obtrusive sources of light.

2. Methods

The article is based on the fundamental assumption of the behaviour of the surface of the modelled billboards. This surface is modelled as a Lambertian surface with a classic LIDC (Luminous Intensity Distribution Curve) of the reflected luminous flux in the form of a cosine function. However, in practice, this LIDC can only be achieved by backlighting the billboard through its diffuse surface or by using an active billboard, such as one with coloured LEDs. Other situations that use lighting systems outside the actual billboard must inevitably distribute part of their luminous flux primarily out of the surface of the actual billboard to achieve the desired uniformity. Thus changing the resulting radiation of the whole billboard into the upper hemisphere. The “whole” is understood in this paper as a combination of the actual billboard, the lighting system, the surfaces near the billboard, and potentially shielding elements of the actual billboard or the lighting systems used to illuminate the billboard.

3. Results

The article presents results based on a model of a billboard illuminated to an average luminance of about 50 cd.m-2 using different shielding elements from below and above position, compared to the basic Lambertian surface radiation. These models, along with the surrounding area of the billboard, are implemented in a software goniophotometer and evaluated in terms of the resulting LIDCs. This means that various types of billboard lighting systems are evaluated in terms of the shape of the LIDCs, taking into account both the direct luminous flux going into the upper hemisphere and the total luminous flux going into the upper hemisphere. The resulting radiation into the upper hemisphere are evaluated in relation to the behaviour of road lighting luminaires and their radiations into the upper hemisphere. Comparing the amount of light emitted by a single billboard to the amount of light emitted by the average road lighting luminaires promises interesting results, particularly in terms of the enormous pressure to reduce the amount of light going into the upper hemisphere from road lighting luminaires, while other lighting systems, perhaps because they are not as clearly defined as road lighting systems, remain outside the scope of public interest.

4. Conclusions

The aim of this article is to use light-technical models of a billboard as an example to highlight the behaviour of different types of lighting systems in terms of their radiation into the upper hemisphere. The results show that when billboards are lit from below, up to 50% of the total luminous flux of the lighting system can be (re)distributed into the upper hemisphere. However, if the orientation of the lighting system is changed and it is placed on the upper edge of the billboard and radiates its luminous flux only towards the ground, the overall emission of such a billboard into the upper hemisphere can be reduced by up to 50%, or to about 25% of the luminous flux output of the installed lighting system. When expanding the assessment to compare luminous flux radiated into the upper hemisphere between the billboard (approx. 92 m^2, 50 $cd.m^{-2}$), very interesting results can be obtained, showing that one billboard emits into the upper hemisphere a light output comparable to 46 average road luminaires when illuminated from below, or 23 average road luminaires when illuminated from above.

Session PA4-3
D1/D2 - Optical properties of materials
Tuesday, September 19, 12:30–13:30

OP31

SOFT METROLOGY OF TRANSMISSION HAZE: AN EXPLORATORY STUDY

Santandreu Oliver, M.[1], Leloup, F.B.[1]
[1] KU Leuven / Department of Electrical Engineering (ESAT), Gent, BELGIUM
Frederic.leloup@kuleuven.be

Abstract

1. Motivation, specific objective

Haze is one of the two optical attributes, next to clarity, that describe surface transparency. Related to human visual perception, haze is defined as the reduction in contrast of an object viewed through a surface, while clarity is related to the loss of detail resolution. From an optical point of view, the reduction of contrast through hazy samples has been attributed to the wide-angle-light-scattering properties of the surface. Standardized methods to quantify haze have been proposed and are available today. E.g., in ASTM Test Method D1003-21, the quantity of haze is defined as the ratio of the light scattered by more than 2.5° from the incident beam direction (diffusely transmitted light) to the total transmitted light through the surface, for a unidirectional illumination. To determine the amount of diffuse resp. totally transmitted light an integrating sphere setup is proposed, containing an exit port on which a light trap can be mounted. Depending on the measurement method, both a unidirectional illumination:diffuse viewing geometry and a diffuse illumination:unidirectional viewing geometry are defined.

Following on the introduction of the standardized test method, commercial haze meters have emerged on the market. While these instruments typically measure haze according to the configuration suggested in ASTM Test Method D1003-21, recently a novel imaging-based approach has been proposed to assess haze and material transmission. An alternative measurement technique based on the analysis and post-processing of pictures is thereby used to identify transparency metrics.

Although the measurement procedures to quantify transmission haze have been standardized, the relationship between the optical measurement and the visual evaluation of haze from the reduction of contrast through a surface has not been extensively examined. In this study, the correlation between ‘optical haze’ and ‘visual haze’ is investigated in detail. For this, measurement results obtained with a conventional haze meter on a dedicated set of samples are compared to visual scales derived from psychophysical experiments under different viewing conditions. Finally, more elaborated measurements are carried out with the aim to understand the optical phenomenon.

2. Methods

A set of 7 circular polymer samples of 27 mm diameter and 1 mm thickness, to which a different concentration of additive powder (SiO_2) ranging between 0.002% and 0.3% is added, was developed for the study.

The transmission haze of all samples was measured with a commercial haze meter (Haze-Gard Plus, Byk Gardner GmbH). Additionally, the Bidirectional Transmittance Distribution Function (BTDF) for normal incidence illumination was determined. For this, a laser source was installed on a near-field goniophotometer, comprising a photometer that is moved around the sample under test.

Next psychophysical experiments were performed to derive a perceptual scale of transmission haze of the 7 test specimen. For this purpose, the Maximum Likelihood Difference Scaling (MLDS) procedure was used. Ten observers were thereby presented 2 pairs of samples with supra-threshold disparities, and asked to indicate for which pair the difference in visual

contrast between the 2 samples is largest. The samples were presented on a sample holder featuring four circular apertures with a contrast pattern, placed on top of a light booth with a diffuser. Multiple sample holders with different airgaps between the sample and contrast pattern were developed to evaluate how this feature impacts the psychophysical assessments.

Finally, the correlation between the measured 'optical haze' and the derived 'visual haze' scales was assessed.

3. Results

The commercial haze meter results indicate that the transmission haze of the 7 test samples ranges between 12% (low haze) and 100% (strong haze). The BTDF characterizes the scattering properties of a material for any angle of illumination or viewing. As such, haze values were derived based on the ratio of diffuse vs. total transmitted light (cf. the ASTM definition) from the BTDF measurements, acquired for normal incident illumination with the near-field goniometer. The comparison between the haze values derived from the BTDF data and the commercial haze meter shows a good agreement. Interestingly, the angular aperture of 2.5º, defined to quantify the amount of diffuse light vs. the total transmitted light, does not seem to be very crucial for calculating optical haze. Indeed, from the BTDF measurement results, a variation in haze of max. 3% can be calculated over all test samples, if the angular aperture for determination of the amount of diffusely scattered light is changed in a range of 1.5° to 4.5°.

From the psychophysical experiments with 10 observers (6 male, 4 female), in which the test samples were assessed in contact with the contrast pattern (no airgap between sample and pattern), a first visual scale was derived. As expected, 'visual haze' increases with contaminant (SiO_2) concentration. Moreover, a clear correlation between 'optical haze' and 'visual haze' (i.e. the reduction in visual contrast) is obtained.

4. Conclusions

The haze and transparency of a dedicated set of samples has been analysed using a conventional haze meter as well as through BTDF measurements. Psychophysical experiments have also been carried out to analyse the haze qualitatively. The proposed methods and evaluation approach work effectively. It has been checked through BTDF measurements that the angular deviation of 2.5° defined in standards to quantify the amount of diffuse transmittance, is not crucial to quantify the haze optically. Moreover, a clear correlation between the perceived contrast reduction and the measured haze values is obtained when the samples are assessed in contact with the contrast pattern. In future research, the influence of an airgap between the sample and contrast pattern on the visual assessment of haze will be investigated.

OP24

UNIVERSAL BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION DATA FORMAT FOR MACHINE-DRIVEN SCIENCE

Aschan, R.[1], Manoocheri, F.[1], Lanevski, D.[2], Ikonen, E.[1,3]
[1] Aalto University, Espoo, FINLAND,[2] LightCode Photonics, Tartu, ESTONIA,[3] VTT MIKES, Espoo, FINLAND
robin.aschan@aalto.fi

Abstract

1. Motivation, specific objective

In several fields of technology and science, the concept of bidirectional reflectance distribution function (BRDF) is used for characterizing, analysing, and visualizing reflected light. BRDF can be given as the ratio of the reflected radiance to the incident irradiance, for a given incident zenith and azimuth angle. The ratio is given in a specific solid angle defined by the detector aperture and the detector-aperture-to-sample distance.

The approach for measuring BRDF varies, but generally goniometric methods are used, which accumulate large data sets. A plethora of measurement methods and unique data processing software produce non-conformities that hinder streamlined collaboration in the community. Most data sets do not comply with the Findable, accessible, interoperable, and reusable (FAIR) guiding principles. Previous standards, such as SEMI ME1392 standard, have proposed BRDF data reporting formats for universal use. However, these standards lack key FAIR concepts, such as missing identifiers and interoperable data formatting. Various BRDF data formats already exist in the industry, including formats used by Zemax, LightTools, and TracePro, but these data formats tend to be specific and proprietary for wide-spread use. Currently, no universal BRDF data format exists. The objective of this work is to remove this inadequacy.

2. Methods

In 2014, the concept of FAIR data was proposed to encourage producing interoperable data sets. Interoperable data, which is structured and uniform, benefits machine stakeholders and humans alike. In 2017, the abundance of non-FAIR data promoted the Joint Research Project “Bidirectional Reflectance Definitions” (JRP 16NRM08 BiRD) to develop a universal BRDF data format for streamlining the process of storing, exchanging, and comparing data in the community. The development of the universal BRDF data format was guided by the FAIR principles. The FAIR concept is a set of high-level domain-independent recommendations for reporting, managing, and sharing scientific data. FAIR recommendations strive for creating interoperable data suitable for machine stakeholders, which would bring them to level with manual users. Our method incorporates rich metadata elements of the FAIR principles into the BRDF format. Rich metadata includes globally and persistently unique identification, uniform labelling, and structured formatting.

The universal BRDF data format will require a flexible structure that can include several dimensions of data. Therefore, we employed the JavaScript Object Notation (JSON) data format. The JSON data format is an open-source and already widely used format that is flexible and lightweight. A flexible format is required since BRDF is a function of various geometrical and optical parameters, including incoming and scattered viewing and azimuth angles, wavelength, and polarization. Furthermore, JSON is software independent and is commonly used for data exchange.

JSON can be easily read by both humans and machines by using JSON data readers in combination with a JSON schema. A JSON schema is a quick method for validating your file to the proposed data format structure, thus ensuring coherence in the workflow.

The JSON data format consists of objects (also known as dictionaries, arrays, etc) that consist of key-value pairs. Keys label values, and values represent the keys as data in various forms, including strings of text, numbers, and other objects. Nested objects allow for lightweight, but complex, and organized data structures.

To promote the FAIR BRDF data format, an open-source application, “BiRDview”, was developed that has several functionalities, including validation of the user data format, comparison of BRDF data and visualizing of BRDF. BiRDview is based on the Plotly Dash open-source framework.

3. Results

The proposed universal and FAIR BRDF data format includes two main objects, “metadata” and “data”. The metadata object describes the BRDF data and its details with additional objects, such as the “schema”, “id”, “instrumentation”, and “sample” objects. The schema object provides a link in the United Resource Identifier (URI) format that allows for continuous development of the open-source data format. The identification, id, object provides a global and persistent identifier, in the URI format, for ensuring findability of the data sets. Other objects in the metadata object describe various details in the BRDF acquisition process, such as specifical details on the instrument or software used for producing the BRDF data, and on the sample specifications.

The data object includes several objects for storing the several dimensions of the BRDF data. Five main fields are required, including the incident and scattering zenith angles, incident and scattering azimuth angles, and the BRDF value itself. The data object is flexible and allows additional dimensionality, including objects for storing the polarization state of the irradiance and the reflected radiance, and the wavelength of the incident beam and the scattered radiance. As a result, the data format is not constrained by the instrumentation or measurement method.

Finally, an open-source web-based software, BiRDview, was developed to promote the use of the universal BRDF data format. The open-source nature of the application allows for community driven development, and the web-based interface allows for a larger audience to participate due to low computer requirements. BiRDview has several functions, including validation of the user’s input files using the BRDF data format schema, comparison of BRDF data sets and visualizing BRDF. The visualization includes 3D plotting, 3D to heatmap conversion, and 2D plotting of any BRDF dimensions.

4. Conclusions

The Joint Research Project “Bidirectional Reflectance Definitions” (JRP 16NRM08 BiRD) introduced a universal BRDF data format that adheres to the FAIR guiding principles. FAIR is a set of high-level domain-independent recommendations that encourages machine-driven science and streamlined exchange of data in the community. The universal BRDF data format is based on the already adopted JSON data format and will incorporate rich metadata from the FAIR guiding principles. To promote general adoption, an open-source web-based application, “BiRDview”, was developed for visualizing the BRDF data format. In conclusion, the adoption of the FAIR BRDF data format in conjunction with the BiRDview application have the potential to facilitate machine-driven science and promote scientific collaboration across various fields, ultimately leading to novel findings.

OP28

EFFECT OF SURFACE CURVATURE ON SPECULAR GLOSS EVALUATIONS

Ged, G.[1], Beuckels, S.[2], Bessenay, T[1]., Audenaert, J.[2], Leloup F.B.[2]
[1] EssilorLuxottica / Lens R&D, Créteil, FRANCE
[2] KU Leuven / Light and Lighting Laboratory, Gent, BELGIUM
gedg@essilor.fr

Abstract

1. Motivation, specific objective

While it has been demonstrated in literature that sample curvature has a significant impact on the visual perception of surface gloss, physical gloss assessment of curved surfaces is not well elaborated yet. The reason for this can be partly attributed to the instrument design of a glossmeter. In essence, when Ingersoll or Hunter built their glarimeter and glossmeter prototypes, the industrial need was to control the surface gloss of high gloss coatings deposited over rather flat artefacts. Almost a century later measurands have significantly evolved. Furthermore, the industrial needs are no longer restricted to controlling the glossiness of flat panels but have extended to the assessment of surface gloss of three-dimensional objects.

The standardized optical design of a glossmeter (cf. ISO2813:2014 or ASTM D523:2018) is solely intended for characterizing flat surfaces but is still widely used over any kind of surface in industry. As such, evaluations of curved surfaces bear non-negligible errors which are often compensated by internal, empiric correction matrices. In addition, the alignment between the glossmeter and the curved surface is crucial and can introduce high measurement deviations. To address this matter, instruments manufacturers designed specular glossmeters with smaller beam diameters (spot sizes of a few millimetres typically), assimilating local surface curvature of the sample to a flat surface. However, by reducing the measurement spot size, local statistics of the surface topography (such as texture or orange peel) might be neglected, particularly for functionalized surfaces. Recently, developments emerged relying on image sensors for evaluations coherent with existing metrics. The availability of image data furthermore introduces opportunities for more accurate and representative measurements.

This study aims to describe the effects of curvature on glossmeter measurements. It discusses an inter-comparison of measurements with different glossmeters over a newly developed sample set with controlled curvature and specular gloss. Bidirectional Reflectance Distribution Function (BRDF) measurements are also performed and discussed, with the aim of explaining the effect of curvature on the measurement results.

2. Methods

Sample sets consisting of nine black samples were created for the study, including four concave samples, four convex samples and one flat sample. Spherical samples were put forward, i.e. the samples present only one curvature radius on the surfaces. Apart from the flat sample, the absolute radius of curvature of the samples ranges between 320 mm and 65 mm. Three geometrically identical sets of samples were developed, each set with its own gloss level (matte, low gloss and high gloss), leading to a total of 27 isotropic samples.

Each sample set was first measured using a commercial specular glossmeter (20°, 60°, and 85°), as to exemplify its measurement limitations. Two more dedicated instruments (both compliant to ISO2813:2014) were further used to characterize the effect of surface curvature: a glossmeter with reduced beam size (20° geometry), and a prototype of a camera-based glossmeter with variable light beam diameter. Dedicated measurement jigs ensure repeatability of measurements and positioning of the instrument on the sample surface. Reproducibility is established with multiple repetitions. The specular gloss (expressed in gloss units - GU) is compared, including the normalised deviations of the curved samples compared to the flat ones.

Finally, BRDF measurements are performed on the flat tiles in the 60° geometry and applied in ray tracing simulations for curved surfaces to predict the reflected specular peak shape and the specular glossmeter measurements.

3. Results

The flat samples have 60° specular gloss values of 88 GU, 10 GU and 2 GU, for the high gloss, low gloss and matte sample, respectively. The measurements with the conventional glossmeter indicate a huge effect of curvature on the specular gloss evaluation. For concave samples, the centre of the sample surface lies below the flat reference level of the instrument, causing the specular gloss to majorly diminish (to 0 GU for the 65 mm radius). Furthermore, only the high gloss samples show a systematic behaviour with a monotonic decrease in specular gloss with (convex or concave) curvature. The results for low gloss and matte samples however indicate complex interactions with curvature and between measurement geometries. The specular gloss measurements deviate due to curvature from a 100 % decrease to 80 % increase compared to the flat sample measurements, with a good reproducibility of the effect.

The reduced beam and image-based glossmeters provide relatively more consistent measurements on the high gloss scale, partly due to improved positioning on the sample surface. In addition, the image-based glossmeter permits evaluation of the reflected image size and deformations, with according adaptation of the specular gloss receptor aperture.

The BRDF measurements with a 60° incidence angle are presented for the flat tiles. Simulated specular peak shape alterations are furthermore presented for the curved samples, according to classical glossmeter apertures. In this sense, it might be possible to simulate the specular glossmeter measurement of curved surfaces.

4. Conclusions

The influence of surface curvature on gloss measurement is becoming more and more important. Compensation for curvature with internally developed scales is however still common practice, lacking both traceability and physical description of the phenomenon.

In this study, a dedicated set of 27 samples with spherical surface curvature and three distinct levels of specular gloss was developed. Specular gloss was determined by aid of multiple conventional glossmeters as well as with a prototype of an image-based system. Curvature induces highly significant errors in the classical specular glossmeter readings, implying that conventional glossmeter measurements are not suited for curved surfaces. Small spot size glossmeters are a possible solution, although limiting the representativeness of measurement to the (reduced) measured surface. Image-based gloss measurement instruments can be put forward as an alternative, allowing for instrument alignment feedback and postprocessing of the acquired reflection image. Finally, BRDF measurements are potential candidates for the future of glossiness characterization of curved surfaces through ray tracing simulations. New physical gloss metrics based on specular peak shape analysis could be constructed for more accurate descriptions of the visual gloss sensation, in the mid gloss to high gloss range.

Session PA5-1
D2/D1 - Temporal light modulation
Tuesday, September 19, 14:30–16:05

OP12

UNTANGLING LIGHT IN “NOISY” LUMINOUS ENVIRONMENTS

Martinsons, C[1]
[1] Centre Scientifique et Technique du Bâtiment, Saint Martin d’Hères, FRANCE
christophe.martinsons@cstb.fr

Abstract

1. Motivation and objectives

The night-time luminous urban environment is a mixture of lights emitted by a variety of sources, including artificial light sources such as streetlights, and natural light sources in the sky. Most artificial lights are used for well-defined purposes: visibility of pedestrians, safety of drivers, signalling, advertisement, etc. Most photons emitted by these common light sources do not finish their course absorbed by the intended sensors (human eyes or digital sensors). They follow complex paths through the built environment, undergoing multiple reflections and transmissions. As a result, artificial light is often found in unexpected locations raising the issue of light pollution associated with undesirable environmental and human impacts. The most emblematic manifestation of the phenomenon is the urban sky glow, made of photons emitted by urban light sources, ending up propagating though higher atmospheric layers where they are scattered by natural and artificial aerosols, veiling the night sky. The urban sky glow reflects the mix of artificial lights at the scale of the whole city. At a smaller scale, the luminous environment seen by people is dominated by nearby luminaires, displays and signs, but also by obtrusive light coming from light sources located farther away, and coming from the sky glow itself. Consequently, the night-time urban luminous environment is “noisy”: it is an ever-changing mix of many light sources of different categories operating with different schedules.

This complexity makes it difficult for local and national governments to enforce and improve the existing regulations on lighting and other luminous installations because in-situ measurements are sensitive to the total light falling on the sensor of measuring devices. The sensor cannot differentiate photons emitted by different categories of light sources. As a result, when measuring the horizontal illuminance given by a road lighting installation, nearby luminous signs and billboards should be switched off, which is not easy to do because they are not managed by the city authorities. Similarly, the vertical illuminance created by a digital display on the façade of a residential building cannot be measured if street lighting luminaires also send light on the façade. Low light measurements are further complicated by the influence of the moon and the natural luminosity of the sky after dusk or before dawn.

The objective of this communication is to present an approach to sort out light in complex luminous environments. It takes advantage of the electrical footprint of artificial lights: their temporal light modulation (TLM) induced by their power supply. A new technology of lock-in detection was recently developed to allow an optical measurement device, such as spectroradiometer, to be locked to the TLM frequency and phase of a given light source, or a given lighting installation, to reject background and parasitic lights that are not modulated or modulated at other frequencies and phases.

2. Methods

Lock-in detection is a well-established technique to measure the amplitude and phase of a modulated signal in the presence of noise, background, and parasitic signals. Lock-in amplifiers are commonly used in many areas to extract small, modulated signals buried in noise.

In the field of optical spectroscopy, lock-in detection is much harder to implement. Compact array spectrometers, at the heart of most spectroradiometers used in photometry and colorimetry, have a high number of output spectral channels, typically of a few hundreds or thousands, far above the capabilities of lock-in amplifiers. A new optical lock-in spectrometry

technique has been developed to provide lock-in detection in a parallel and multichannel fashion for all the spectral output channels. It relies on phase and quadrature modulation applied at the entrance slit of two identical compact array spectrometers using synchronized optical modulators. The synchronization signal is provided by the temporal light modulation waveform of the light beam to analyse.

A remote sensing setup was designed to measure the temporal light waveform at long distance and provide the synchronization signal to the optical lock-in spectrometer. The setup is based on an astronomical telescope, a photodiode, an amplifier, and an analogue to TTL converter. This device can measure the temporal light waveform of an artificial light source at distances exceeding 100 m.

The measurement input of our optical lock-in spectrometer can be connected to an irradiance head to measure spectral irradiance. It can also be connected to a second astronomical telescope fitted with an optical fibre to measure spectral radiance.

When measuring a “mixture of light”, the light component to extract is chosen by pointing the synchronization telescope to the light source of interest.

3. Results

The implementation of optical lock-in spectrometry was first demonstrated in the laboratory and provided insights about the physics of different lamp technologies, based on the spectral variations of their temporal light modulation.

A second series of experiments was carried out in a typical indoor lighting configuration. The experiments consisted in untangling the individual spectral irradiance distributions of several lamps illuminating a sensor at the same time, on top of a large continuous background. The photometric and colour parameters of each lamp were successfully retrieved, demonstrating the interest of this technique to perform measurements in noisy luminous environments.

A new series of experiments is being carried out to measure from a long distance very small levels of obtrusive light on façades and streets illuminated by several light sources, including natural light at dawn or dusk.

4. Conclusions

A new optical spectroscopy has been developed to enable lock-in detection, an efficient technique to reject background and parasitic lights.

When performing measurements of artificial light sources such as luminaires, signs and displays, optical lock-in spectrometry takes advantage of temporal light modulation, which is the “electrical footprint” of artificial lights, to select and extract the contribution of a given light source from the complex and noisy luminous urban environment.

This technique can be applied to remote sensing measurements to facilitate compliance testing of signs, luminaires, and displays in their normal environment without turning off other light sources.

The capability of optical lock-in spectrometry to sort out the contributions of different light sources and to detect low light levels against a bright background could also be used to identify light fluxes emitted upwards, directly, or indirectly through surface reflections, contributing to a better knowledge of the formation of the urban sky glow.

OP21

TOWARDS A COMPREHENSIVE CALCULATION OF MEASUREMENT UNCERTAINTY FOR TEMPORAL LIGHT MODULATION

Thorseth, A.[1],
[1] Technical University of Denmark, Roskilde, DENMARK
andt@dtu.dk

Abstract

1. Motivation, specific objective

Temporal light modulation (TLM) is of interest due to the combination of widely used and easily modulated LED light sources and the receptibility of humans and animals to modulation in visible radiation. Regulation of TLM is present in various jurisdictions and therefore rigorous measurement techniques and measurement uncertainty estimation is of critical importance, to get reliable characterisation of TLM in product testing and field measurements.

It is the objective of this study to describe components and methods needed to perform estimation of the measurement uncertainty, pertaining to the calculation of metrics for evaluation of TLM such as stroboscopic visibility measure (SVM) and short-term flicker severity PstLM. Since TLM metrics are calculated by complicated algorithms from a large amount of data then propagation of uncertainty becomes important. Traditional propagation of uncertainty using partial derivatives through such complicated algorithms, can be cumbersome while the computational power, used to perform the parameter analysis and Monte Carlo analysis used in this study, is more readily available.

It is a complication that the measurement of TLM involves a high number individual measurement points, i.e. the points constituting the measured waveform. Each point of the waveform has its own measurement uncertainty both regarding amplitude and time, and this uncertainty needs to be estimated and propagated to the final result.

The points in the waveform are generally highly correlated, as most points are the result of processes that are repeated for every short cycle of the TLM with repeating frequency of 100 Hz or similar, exceptions being values dominated by noise.

CIE TC 2-89 is in the process of a technical report on TLM including measurement uncertainty and this work will be in support of that.

2. Methods

It has already been shown that the effects of various uncertainty contributions are strongly dependent on the incident waveform shape. For demonstrating the effect of uncertainty of various measurement parameters on various waveforms, predefined reference waveforms are being employed, as input to a model calculation.

The methodological approach is to model various effects such as offset, noise and filtering and then pass reference waveforms through one or more models while varying the model parameters. The next step is to propagate the waveform through the TLM metric calculation (SVM, PstLM etc.). And lastly investigating the results, in terms of sensitivity, value dispersion etc.

For some parameters the effect can be investigated by simple variation (systematic effects) while for others one needs to employ Monte Carlo methods to investigate the effect of random contributions such as electronic noise.

One focus of this study is filtering, as TLM measuring equipment generally has to include analogue filters to prevent aliasing, however the filter characteristics can cause measurement uncertainty if not properly characterized, and therefore has to be included in a model and propagated to the TLM metric calculation.

Using this approach also enables investigations into how various experimental parameters may amplify or negate the effect of each other, by passing the waveform through several models before calculating the result.

3. Results

Preliminary results show that the approach presented can be used to bound the size of uncertainty contributions between best-case and worst-case scenarios. The approach presented delivers individual sensitivity coefficients for systematic effects and dispersion of values where the input are random variations of a given parameter. The specific parameters and parameter uncertainty, such as contributions from specific components in the signal chain may need to be investigated by other means.

The preliminary results also show that a general modelling approach can provide guidance towards the most critical uncertainty contributions. This is not necessarily only due to the size of variations derived from the measurement situation but also importantly from the influence of model variations to the incident waveform. Having the same uncertainty model components work on different waveforms may cause estimated measurement uncertainty contributions of very different sizes. It is also found that the TLM metric have very different sensitivities especially regarding noise.

4. Conclusions

Modelling and simulation of TLM measurement uncertainty effects are viable as a way to estimate sensitivity coefficients of various parameters. For some parameters simple parameter variation can be used. For stochastic uncertainty contributions Monte Carlo simulation is a viable method to estimate the influence of random variations in the input, on the distribution of the output variable i.e. TLM metric. The approach gives estimates for parameter sensitivities or dispersion of the output and combined with the parameters uncertainty one can derive the combined measurement uncertainty.

Although not necessarily representable for all possible measurements, predefined reference waveforms can give an indication of the type of uncertainty to be expected, given that there is defined a reference waveform more or less similar to the one being measured. The approach is best suited to model compound effect such as overall noise and not specific sources of uncertainty from specific elements in the measurement chain.

OP62

UTILIZING THE ROLLING SHUTTER OF ACTIVE PIXEL MATRIX SENSORS TO PERFOM QUALITATIVE MEASUREMENTS OF TEMPORAL LIGHT MODULATION

Ledig, J.[1], Lindén, J.[2], Stein, A.[1]
[1] Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, [2] Division of Ergonomics and Aerosol Technologies, Design Sciences, Lund University, Lund, SWEDEN
johannes.ledig@ptb.de

Abstract

1. Motivation, specific objective

Smart lamps that are dimmable or variable in color often exhibit significant temporal light modulation (TLM), namely when not operated at full load and when realized by pulse width modulation (PWM), e.g. for each channel of tunable white or RGB-LEDs. The implemented TLM mode is in most cases not declared by the specification of the lighting product and not easily assessed by bare eye, but it can lead to temporal light artifacts (TLAs). Regarding tunable lamps also color breakup inside the stroboscopic effect or phantom array effect is a prominent artefact. This TLA is not rendered by flicker metrics nor by the stroboscopic visibility measure (SVM).

Digital RGB cameras exhibit a significant spectral mismatch with respect to the photometric standard observer and corrections are usually just dedicated to color rendering of image reproductions and artwork, i.e. image styles. But their sensor signal can anyway give qualitative assessment of contrast in luminance and color. In addition, most CMOS-based active pixel matrix sensors (APS) usually include one analogue to digital converter (ADC) per column to which all pixel signals inside the column are multiplexed, resulting in subsequent sampling of pixel rows which is referred to as a rolling shutter readout mode. This represents a temporal sampling across the image which can lead to artefacts when imaging fast-moving objects but can also render TLM.

Most APS utilized in consumer cameras, i.e. in smartphones or compact cameras, provide a rolling shutter that typically corresponds to a sampling speed in the 10 µs range. This interleaved sampling of rows in the time domain is smoothed by the integration time per pixel, i.e. a few 10 µs to a few 10 ms, which thereby acts as an analogue low-pass filter. The objective of this paper is to demonstrate that this imaging mode can reveal TLM of smart lamps in a qualitative way.

2. Methods

In this study individual lamps based on different technology (i.e., incandescent, fluorescent, or LED lamps) are imaged by consumer cameras with a rolling electronic shutter. In addition, lab-based experiments with TLM standard sources are used to verify this measurement method and to demonstrate quantitative inadequacies.

These are arranged to represent extended sources with respect to the camera field of view, i.e. by its diffuse light emitting area. Small sources are positioned out of focus, e.g. close to the lens, so that their unsharp image covers many pixel columns. In case of intense sources that overexpose the pixels it is possible to investigate image regions dominated by stray-light.

Profile plots are extracted across the columns of these images and represent the waveform with respect to the different color channels. Regions that are within the dynamic range, i.e. not clipped by the ADC range, are compared to waveform measurements obtained by photometric flicker meters and by a tristimulus measurement head.

3. Results

The measurement of different lamps that exhibit TLM resulted in clear examples which demonstrate the respective TLM mode and the most significant TLM parameters, e.g. periodicity and PWM duty cycle. In addition the multispectral RGB images also qualitatively reveal temporal color modulations, e.g. of tuneable white or RGB-based LED lamps. The examples give a clear representation for an operation of LED channels with TLM phase shifted to another or by temporal multiplexing of LED channels with a global dimming PWM.

The sampling sequence inside a single image covers a few 10 ms and in most cases corresponds to a few waveform periods. This is sufficient to judge the TLM periodicity of smart lighting products and thereby tentative severeness regarding TLA - but is quite limited compared to conventional flicker meters. The rolling shutter sampling rate of an individual camera can be estimated using a lamp which waveform renders the mains frequency.

A variation of imaging parameters demonstrate that the temporal resolution is dominated by the integration time as an analogue low-pass filter. In addition it is revealed that the sampling rate sometimes changes with the parameter settings and that the resulting waveform is often affected by post processing, i.e. converting the pixel data to conventional image formats or by local tone mapping, which can be avoided by monitoring the camera parameters and evaluating the raw image data.

In automatic mode relevant parameters of such a measurement are unknown or not controlled, e.g. the sensor gain (named ISO setting), integration time, or post-processing. Also the readout mode and therefore shutter speed depends on the setting and their relation might be altered by a firmware update.

4. Conclusions

Utilizing the rolling shutter for qualitative measurements of TLM is demonstrated to be a well performing approach giving a valuable insight to the operation principle of lamps, i.e. to judge which type of waveform modulation and periodicity is present. Namely regarding the diverse driving schemes of smart lighting products such qualitative measurements can compensate the general lack of corresponding SSL product specifications.

The investigation demonstrates that APS can provide a vivid insight to TLM with a periodicity of 50 Hz up to a few kHz, which covers the relevant frequency range for prominent TLA metrics such as SVM. By means of smartphones the related hardware is already present in the entire society and right away capable to reveal and verify the TLM mode of most SSL products. Constrains like support of a high frame rate, e.g. dedicated for slow motion videos, are not necessary.

The results demonstrate that the temporal resolution of the waveform is just limited by the pixel integration time rather than the sampling rate. In addition, these examples are suitable to quickly train about how to adjust the camera parameters for revealing the qualitative waveform with a sufficient temporal resolution or to avoid artefacts from TLM inside a photo. The results also revealed that an accurate or quantitative evaluation requires extensive characterization of the camera and monitoring of its parameters, while in most cases the relative waveform type of conventional lamps, tuneable white or RGB LEDs can be judged right away from an image.

OP80

SYSTEMATIC ERRORS OF TEMPORAL LIGHT MODULATION METRICS RELATED TO SAMPLING DURATION

Stein, A.[1], Wiswesser, P.[1], Ledig, J.[1]
[1] Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
annika.stein@ptb.de

Abstract

1. Motivation, specific objective

Smart lamps that are dimmable or variable in color (i.e. tunable white) often exhibit significant TLM, namely if not operated at full load and in case dimming is implemented by means of PWM. TLM can lead to temporal light artifacts (TLAs) and can have a negative impact on the health, well-being and safety of humans or animals. Therefore, the new EU Ecodesign Regulation 2019/2020 "Uniform Lighting Regulation" sets limits for TLM. The CIE Technical Note TN 006:2016 defines three types of TLA: flicker, stroboscopic effect, and the phantom array effect. Metrics are already recommended by the CIE for the evaluation of flicker and the stroboscopic effect. In this work, systematic errors and uncertainty contributions related to the sampling duration with respect to the periodicity of the waveform are to be shown and estimated

2. Methods

In this study, beside conventional flicker meters also high-speed cameras and imaging luminance measurement devices are used to visualize and evaluate TLM in real light scenes. Scenes including multiple light sources under laboratory conditions but also field demonstrations have been performed. The metrics Flicker index and SVM are calculated from the image sequences, among others. Short sampling durations are preferred for measurements using imaging measurement devices because the imaging measurement correspond to a huge amount of data.

Systematic errors related to the sampling duration are investigated also by simulations on exemplary nominal waveforms. This reveals the issue by clear examples and allow to discuss the error interval for the mean value and the TLA metrics.

3. Results

The short sampling duration leads to a considerable uncertainty contribution in the calculation of the flicker index and the SVM. For both calculations, the average value of the signal is a crucial quantity inside the denominator. The calculation of the average value is calculated for each sample point and is only correct at the time of each complete waveform period. At the time of fraction of a number of periods the calculated average value oscillates around the actual average value while the error interval depends on the waveform, i.e. it gets most significant for pulse waveforms of short duty cycle, and converges to zero for long sampling durations. With a sufficiently large sampling duration in terms of number of complete waveform periods recorded, the resulting error becomes sufficiently small compared to other uncertainty contributions when the sampling duration is a fraction of a number of periods. This is not achieved for a short sampling duration. For short sampling durations, the calculation of the average value of the waveform and other parameters depending on it, must be done exclusively from a sampling sequence that corresponds to an integer number of waveform periods.

4. Conclusions

The systematic error and therefore the related uncertainty contribution from the average value calculation of a waveform increases significantly when the measurement duration is shortened. For short sampling durations, attention must be paid to evaluate a sampling sequence that corresponds to an integer number of waveform periods for calculating the flicker index and the SVM. If this is not observed, a PWM-waveform with a very small duty cycle and a small fractional deviation from an integer number of periods can lead to a significant error in the average value, i.e., of up to 30 % then considering slightly above three periods. This also affects the inaccuracy of the calculation of the metrics flicker index and SVM. Considering a small deviation from 100 periods, the error is reduced to 1%, but this is still not just negligible but to be considered as an uncertainty. For a sine or triangular shape, the error is highest at half periods and is 10% when considering 3.5 periods.

OP60

DEPENDENCE OF TEMPORAL FREQUENCY AND CHROMATICITY ON THE VISIBILITY OF THE PHANTOM ARRAY EFFECT

Kong, X.[1], Vogels R.[1], Martinsons C.[2], Tengelin M.N.[3], Heynderickx I.[1]
[1] Eindhoven University of Technology, Eindhoven, the NETHERLANDS, [2] Centre Scientifique et Technique du Bâtiment, Saint Martin d'Hères, FRANCE, [3] RISE Research Institutes of Sweden, Borås, SWEDEN

x.kong@tue.nl, r.c.h.vogels@student.tue.nl, christophe.martinsons@cstb.fr, maria.nilssontengelin@ri.se, i.e.j.heynderickx@tue.nl

Abstract

1. Motivation, specific objective

Multiple studies have measured the visibility of the phantom array effect as a function of variables, such as temporal frequency, luminance/illuminance, size of the light source, saccade speed of the observers, and colour of the light. The effect of temporal frequency on the visibility of the phantom array effect is not surprising, since the human visual system is sensitive to spatial and temporal frequency of light. However, how the visibility of the phantom array effect changes with the temporal frequency is still not consistently answered in literature, and therefore, needs additional measurements. A provisional model of the visibility of the phantom array effect for a point light source based on the spatial contrast sensitivity function was described in CIE 249:2022; it predicted a sensitivity peak of around 1000 Hz. Some experimental investigations, however, showed a peak at about 600 Hz, while others concluded that the visibility decreased as the temporal frequency increased, and that the phantom array effect was even visible at very high frequencies of above 15 kHz. Since for the design of visually safe light sources it is crucial to understand when the phantom array effect becomes visible, we performed new measurements on its frequency dependency.

Both spatial and temporal contrast sensitivity functions are colour-dependent, thus the effect of colour on the visibility of the phantom array effect is expected. This colour dependency has been reported in multiple studies. Since in these studies, different luminaires (i.e., with different chromaticities and peak wavelengths) and settings (i.e., different intensities and viewing geometry) were used, it is challenging to compare the results directly. Hence, to understand the effect of colour on the visibility of the phantom array effect also, additional measurements are needed.

In summary, our motivation is to investigate the effect of temporal frequency on the visibility of the phantom array effect, with a special interest in where the peak is and how the peak frequency changes with chromaticity. Our dataset, together with other available data in the literature, can be used to model the sensitivity function of the phantom array effect in the future.

2. Methods

To measure the visibility threshold of the phantom array effect, we conducted a psychophysical experiment. A calibrated, customized set-up was used, which mainly consisted of a power supply, a programmable waveform generator, and a luminaire consisting of multiple rows of high-power white LEDs (CCT = 2700K), colour filters, and diffusers. The TLM (temporal light modulation) luminaire was placed behind a thin vertical slit (i.e., 0.3 cm × 15.22 cm), which subtended a visual angle of 0.2 ° (horizontally) × 10 ° (vertically) when being viewed by the participants at a distance of 87 cm. The temporal frequency and modulation depth of the luminaire were controlled via TCP/IP protocol by a laptop running MATLAB. Light stimuli with different chromaticities were realized by placing colour filters in front of the white LEDs. In such a way we created red (x = 0.69, y = 0.31), green (x = 0.24, y = 0.70), and warm white light (x = 0.47 , y = 0.41; CCT=2700K). All light sources had a constant luminance level of 50 cd/m^2 (i.e., measured by a photometer at the centre of the thin slit). The experiment was conducted in a dark room (i.e., < 1lx).

The experimental protocol was approved by the institutional Ethical Review Board. Participants were presented with two light stimuli sequentially, either a temporally modulated light stimulus or a light stimulus that was driven with a direct current (DC). Such stimuli pairs were presented in a counterbalanced order, and the task of the participants was to indicate in which of the two stimuli the phantom array effect was observed (i.e., a two-interval forced choice (2IFC) task). An adaptive psychophysical procedure named QUEST+ was used to change the modulation depth of the sinusoidal waveform in the next stimuli pair based on the participant's previous responses.

A pilot study showed that the experiment was very tiring for the participants. To limit eye fatigue, we used a fractional factorial 3 (colour; red, green, and white) × 6 (temporal frequency; 80 Hz, 300 Hz, 600 Hz, 900 Hz, 1200 Hz, and 1800 Hz) within-subject design, in which all participants were presented with three frequencies and two colours. Twenty participants (eleven male, nine female), aged between 19 and 32 years old (mean = 24.2, std. = 3.4), participated in the experiment.

3. Results

The visibility threshold was expressed as the modulation depth of the sinusoidal waveform, varying between 0 (i.e., DC light) and 100%. In total, we collected 120 thresholds (= 20 participants × 2 colours × 3 frequencies). These thresholds were extracted from the percentage of correct responses as a function of the modulation depth, i.e. a so-called psychometric function. We chose the 'Weibull' cumulative distribution function as the psychometric function to fit to our data, using the maximum likelihood method. From these fits, we determined the visibility threshold as the modulation depth corresponding to the 75% correct point on the psychometric curve (since we used a 2IFC method, for which pure guessing corresponded to 50% correct). An ANOVA showed that there is a significant effect of frequency ($F(5, 83) = 27.33$, $p < .001$) at a 95% confidence interval. But no significant effect of colour ($F(2, 83) = 0.86$, $p = .425$) was found. The interaction effect between colour and frequency was not significant either ($F(10, 83) = 1.69$, $p = .098$). The visibility peaked at 600 Hz for all three chromaticities.

4. Discussion and conclusions

Our results showed that a bandpass-shaped sensitivity function for the phantom array effect with a peak at 600 Hz was found for all three chromaticities. The peak differs from the provisional model presented in CIE 249:2022, in which the sensitivity peaks around 1000 Hz at a luminance of 1000 cd/m^2. In our study, the luminance was 50 cd/m^2, which might explain the discrepancy partially. Substantial individual differences in the visibility thresholds were found as well. The effect of chromaticity was not confirmed, but this could probably be explained by the difference between using filter-based different chromaticities or tunable light sources. How big this difference is, can be investigated with future studies using different chromaticities with narrow-banded LEDs. In summary, our experiment has shown that for different filter-based chromaticities at 50 cd/m^2, the visibility threshold of the phantom array effect is lowest at a temporal modulation of 600 Hz.

Session PA5-2
D3/D2 - Daylight

Tuesday, September 19, 14:30–16:05

OP1

CONTINUOUS OVERCAST DAYLIGHT AUTONOMY: A NEW SENSOR-LESS ALGORITHM FOR LIGHTING SMART CONTROLS

Acosta, I.[1], Campano, M.A.[1], Fernandez-Aguera, J.[1], Bustamante, P.[1]
[1] Instituto Universitario de Arquitectura y Ciencias de la Construcción, Universidad de Sevilla, 41012 Seville, SPAIN
iacosta@us.es

Abstract

1. Motivation, specific objective

In the current context of building design, promoting energy savings is essential to achieve sustainable construction. Since electric lighting accounts for 15-30% of operational energy consumption in buildings, a suitable use of natural lighting must be considered in the architectural conception. Therefore, most research on architectural lighting focuses on improving passive design to increase the use of daylighting, optimizing daylight-linked control systems, while considering illuminance requirements and avoiding sunlight and glare.

Given this scenario, questions could be raised as to why daylight-linked controls are not more commonly used in modern architectural design. According to various authors' findings, the answer lies in factors such as the expense of installation, the unsuitable effect of where photosensors and occupancy detectors are placed—usually in the ceiling—and the unpredictable actions of occupants.

According to the background described, a new dynamic metric is suggested that can be integrated as an algorithm to dim the luminous flux of the lighting fixtures according to conservative assumptions such as solar altitude and the Daylight Factor (DF) given under overcast conditions, with no need for internal devices. Therefore, the typical inconveniences of daylight-linked controls, such as the calibration, the installation costs and the effects of the sensors' position, are avoided.

This novel metric, defined as Continuous Overcast Daylight Autonomy (DAo.con), quantifies the time throughout the year when an illuminance threshold is met solely by daylight under continuous overcast sky conditions, providing a linear partial credit to those values below the defined threshold.

In accordance with the current context of daylight design in architecture, dynamic metrics give a noticeable variety of procedures for quantifying the energy consumption related to different lighting configurations, so it is worth considering whether a new metric is truly necessary. The usefulness of DAo.con lies in its ability to act as a control algorithm—by means of its weighting factors—dimming the luminaires without a light sensor, only requiring DF, geolocation, illuminance threshold and occupancy hours.

2. Methods

The calculation procedure of DAo.con can be described from an analytical approach; solar altitude allows to quantify the zenith luminance under a cloudy sky and accordingly the outdoor illuminance throughout the year. The ratio of the indoor to the outdoor illuminance measured under overcast sky conditions serves to quantify DF, which is an invariant result irrespective of location or window orientation. Knowing the outdoor illuminance under overcast sky as a function of solar altitude, along with DF, the indoor illuminance can be determined under a cloudy sky for any specific time of the year. After this procedure, DAo.con can be determined, quantifying the energy saving allowed by a dimming control according to the theoretical indoor illuminance under overcast sky.

The weighting factors provided by the proposed metric—which correspond to the ratio of the indoor overcast daylight to the illuminance threshold for each time interval—serve to modify

the luminous flux of the luminaires and therefore the indoor illuminance given by electric lighting during the occupancy time, guaranteeing that the inner light measured under real conditions will be equal to or higher than the required, since statistically speaking the cloudy sky usually presents the worst-case scenario.

3. Results

Firstly, a validation of the dynamic metric suggested is conducted by comparing the simulation results with those obtained from a test cell operating under real sky conditions throughout 2017. The test cell is defined as a room 2.40 m wide, 3.20 m deep and 2.70 m high with a single window which faces south, located in Seville. The illuminance values that determine the dynamic metrics are measured by a mesh of illuminance-meters placed on the floor. The difference between the simulated and the measured DAo.con values corresponds to 1.0% with a standard deviation of 8.8%, showing accurate results of the simulation procedure based on the DF calculation using the Radiance Engine.

Secondly, a simulation procedure, previously validated, is carried out with the aim to quantify the benefits of the proposed metric, applied as an algorithm for a sensor-less control system. A typical office room 3.00 m high with a variable depth between 6.00 and 9.00 m is studied. DAo.con algorithm provides scenarios for energy saving based on the application of its weighting factors for dimming the luminaires according to an assumed cloudy sky, highlighting a light hardware footprint.

The reduction of energy consumption provided by the presented algorithm is observed between 26 and 69% depending on the opening size—window to façade ratio between 60 and 90%—. Quantifying the prior assertion, the weighting factors of DAo.con allow an energy saving of electric lighting between 5.8 and 6.8 W/m^2 for locations with predominantly clear skies and between 2.3 and 3.3 W/m^2 for mainly cloudy locations, considering a 6 m depth room with a medium-size or large window and a maximum lighting consumption of 9.0 W/m^2.

4. Conclusions

The sensor-less lighting system controlled by the weighting factors of DAo.con metric serves as a valuable tool for reducing energy consumption in buildings. Although it offers fewer benefits compared to lighting controls based on indoor devices, the new algorithm provides remarkable energy savings in most scenarios. The system achieves an average reduction of the luminous flux of the lighting fixtures of almost 70% at a distance of 3 m from the window and close to 35% at a depth of 6 m. Its simplicity, low installation cost, and no impact on the user's environment are its greatest advantages. It is worth noting that this algorithm offers better results in certain cases than a switching system controlled by indoor photosensors—rooms with mainly clear skies and small or medium-size windows—, confirming the usefulness of this sensor-less lighting system. Consequently, widely implementing this system in building lighting design is desirable.

OP26

SKYSPECTRA: AN OPENSOURCE DATA PACKAGE OF WORLD-WIDE SPECTRAL DAYLIGHT

Balakrishnan, P. and Knoop, M.
Fachgebiet Lichttechnik, Technische Universität Berlin, Berlin, GERMANY
priji.balakrishnan@tu-berlin.de

Abstract

1. Motivation, specific objective

In recent years, the importance of the spectral characteristics of daylight has grown significantly in the field of lighting design, application, and simulation. This is due to the increasing body of research demonstrating the visual spectrum's impact on our non-image-forming responses to light and well-being. Thus, there has been a need to include spectral daylight data of the sun and the sky, e.g. spectral global irradiance and spectral radiance, in daylight prediction tools, resulting in various approaches to model or collect this data. These approaches include standardized spectral distributions, sky models, or physics-based radiative transfer models, as well as using RGB sensors or cameras to quantify, estimate, or predict spectral daylight data.

A well-documented dataset that represents different geographical locations, seasons, atmospheric conditions, or times of day is often necessary to validate these models or data collection methods. However, spectral sky scanners, radiometers, or photometers are expensive measuring devices and require specialized setups to capture spatial or hemispherical spectral sky data. Moreover, most meteorological sites do not measure spectral sky radiation. While various specialized long-term or short-term spectral sky measurement initiatives exist, the type of spectral sky measurement, mode of storing data, and measurement location vary. Therefore, this paper aims to present an open-source data package that collects and standardizes spectral daylight measurement data of the sun and the sky from specialized sources worldwide. By compiling this data into a homogenous and comprehensive sample spectral daylight dataset, we hope to facilitate further research and development of daylight applications that utilize spectral sky data.

2. Methods

To initiate a global measurement collection campaign for spectral daylight, a Commission Internationale de l'Eclairage Technical Committee (CIE TC) 3-60 on Spectral Daylight Characteristics was established in 2022. This paper presents long-term and short-term measurement datasets from various locations, including data from CIE TC members and publicly available sources.

To ensure standardization of the collected data, functions are developed in R programming language to organize the data into a tidy format. The approach follows consistent naming conventions, format and units for each column name and values. This organized format facilitates efficient data manipulation, analysis, and visualization of the collected data as a group.

The structure of the data package is described as follows: it contains a sample dataset from various locations, which are organized into measurement datasets and supplementary datasets. The measurement datasets comprise four data frames, each representing a different type of spectral sky measurement: spectral global horizontal irradiance measurements, spectral global tilted irradiance measurements, spectral direct irradiance measurements (of the sun), and spectral radiance measurements patch-wise. The supplementary datasets, on the other hand, include additional information for each measurement and are organized into the following data frames: location, weather, sun positions, and measurement device information.

3. Results and conclusions

The open-source data package will be released as a repository, accompanied by an R vignette and interface package. The R vignette and interface package will provide a user-friendly interface for accessing and utilizing the open-source data package. The vignette will offer a comprehensive guide on how to use the package and the underlying data, while the interface package will simplify data access and usage for users. The CIE TC 3-60 committee is planned to continue until end of 2024, and therefore, a sample of the dataset will be made available along with this paper. Following the completion of the CIE TC 3-60, the data package and R functionalities will be updated accordingly.

OP73

DAYLIGHT REQUIREMENTS: AN OVERVIEW OF DEFINITIONS, PROGRESS AND GAPS

Pinheiro, A.M.[1] Amorim, C.N.D.[1]
[1] University of Brasília, Brasília, BRAZIL
ap.arquiteturas@gmail.com

Abstract

1. Motivation, specific objective

Daylight has significant relevance in the built environment for its visual and non-visual effects, the potential for energy efficiency, and wellness promotion. However, design embodying daylight is complex: it requires from the designer a wide comprehension of how daylight strategies affect space's performance, which is not always clear, neither during education, nor in practical experience. Daylight requirements embrace the necessities linked to natural light in the built environment, whether to develop specific tasks or to obtain non-visual effects. Daylight metrics are requirements that define, describe, and measure the behavior of daylight in the built environment. The article aims to track daylight metrics' evolution over time and the gaps in reference documents for building design. As it corresponds to a initial phase of a wider research, the article focused only on the visual effects, since they are better consolidated than the requirements and metrics regarding non-visual effects.

2. Methods

This article conducts a systematic literature review (SLR) that aims to find progress, gaps, overlaps, application and how harmonized are daylight metrics in documents regarding building construction, such as standards, rating systems, urban codes, and building guidelines. The search for the SLR was conducted through search strings to find relevant papers (Dresch et al., 2015). The search used three main databases: Scopus, Web of Science (WoS) and Google Scholar, choosing papers published in journals from 2015 to 2022. The results found in WoS were the same as those found in Scopus. The first criterion to select papers was open access. Papers published before the defined time frame, found in other papers' references, were also included, due to the relevance to the theme. Next, the articles went through a second filtering, based on adhesion to the theme, where medium and high adhesion articles were selected for full reading.

3. Results

Based on the SLR, the most recurrent metrics were Daylight Factor (DF), Daylight Autonomy (DA), Useful Daylight Illuminance (UDI), and Daylight Glare Probability (DGP). A significant progress found is that metrics evolved from static to dynamic, though DF remains widely used even with its limitations. Nevertheless, dynamic metrics express better daylight, since they reflect the real climate conditions, providing more realistic results. The most relevant gaps are that there is a lack of studies approaching the use of daylight requirements in urban and building codes and design guidelines, and that there is low harmonization of daylight requirements among documents. Also, papers discussing daylight requirements in building design guidelines and manuals were not found. The search for daylight requirements in urban codes was unfruitful, since there were no studies found discussing intersections between daylight requirements or metrics and land use laws or urban codes. As observed by the lack of discussion of daylight metrics in various reference documents, more studies are necessary to support robust attempts to harmonize daylight requirements.

4. Conclusions

Since the 2000s, daylight requirements have improved quickly, whether to deeper comprehend the effects of daylight on humans, or to find a way to predict daylight behavior during design steps. There is no consensus about which metric is the best or most representative, fact that defies designers to work with documents with parameters with little or

no overlaps. So, the search for consensus has paramount importance to provide daylight quality in design activity and promote pleasing and healthier spaces.

OP15

IMPLEMENTATION OF SPECTRAL SKY DEFINITIONS IN A LIGHTING SIMULATION TOOL AND COMPARISON TO SPECTRAL MEASUREMENTS

Orman A.[1], Safranek S.[2], Pierson C.[1]
[1] Oregon State University, Corvallis, Oregon, UNITED STATES, [2] Pacific Northwest National Laboratory, Richland, Washington, UNITED STATES
ormanova@oregonstate.edu

Abstract

1. Motivation, specific objective

People's light exposure patterns have changed tremendously as we shifted to spending 90% of our time indoors and made electric light readily available and used at any point of the day. The discovery of intrinsically photosensitive retinal ganglion cells (ipRGCs) in the eyes and their effects on the health and wellbeing of people has raised awareness of the importance of our exposure to light. The ipRGCs constitute a new class of photoreceptors that produce melanopsin, a photopigment, when light reaches the retina. The expression of melanopsin mediates ipRGC-influenced light responses in people. These responses play a role in regulating our physiological, behavioural, and psychological processes such as synchronization of the circadian rhythms to the light/dark solar cycles, alertness, or long-term health of the body and mind function. The responses depend on different aspects of the light exposure primarily the intensity of light, duration of exposure, light history, and spectral content. To describe light exposure in the context of non-visual responses to light, the CIE recommends the use of a framework based on five α-opic spectral sensitivity functions, quantities, and metrics. To apply this framework, new spectral light simulation tools have been developed.

Similar to traditional simulation tools used for lighting design and analysis, new spectral light simulation tools predict the light interactions between the sources and the scene. The differences between them lie in higher spectral resolution and spectral definitions of materials, electric light sources, and the sky in the scene.

Lark is one of these spectral light simulation tools that is based on *Radiance* and offers a 9-band spectral resolution. It is a free and open-source tool that runs on the *Grasshopper* plugin in *Rhinoceros 3D*. In the latest released version, *Lark* (v2.0) utilizes the CIE Standard Illuminant D65 or a user-defined sky spectral power distribution (SPD) input to create a spectral sky definition for the scene. This approach can be limiting. On one hand, custom sky SPD measurements are not available to most users. On the other hand, while a recent validation study of *Lark* reported a relative error within the ±20% range when using the D65 Illuminant for the spectral sky definition, a spectral sky definition based on the D65 Illuminant may not be accurate for some locations, weather conditions, or times of the day/year due to overgeneralizing assumptions about the sky spectral content.

For these reasons, this study aims to determine whether Lark's accuracy improves when a spectral sky model is used for the spectral sky definition. *Occupants Wellbeing through Lighting (OWL)* is another free and open-source tool that runs on the *Grasshopper* plugin in *Rhinoceros 3D*. OWL uses a spectral sky model to generate a spectral sky definition that is appropriate for a specific location, weather, and time of the day/year. In this study, we implemented *OWL* in the *Lark* framework and compared the simulation outputs against daylight measurements to evaluate the change in *Lark's* accuracy if *OWL* spectral sky definition is used.

2. Methods

Spectral irradiance measured at three desk positions in a daylit office-like environment is compared to the spectral irradiance at corresponding positions in a simulation model predicted by *Lark* using the D65 and the OWL spectral sky definitions.

The office-like environment in two locations has three desk positions each presenting a different orientation in respect to the only window in the room. One desk faces the window, the second one looks at the wall in between, and the third position faces the wall opposite of the window. The window orientation is south for first location and west for the second.

The simulations were conducted using *Lark* v2.0 and *OWL* v1.0. The first set of simulations, named *Lark+D65*, were run using the D65 Illuminant for the spectral sky definition as originally implemented in *Lark v2.0*. For the second set of simulations, named *Lark+OWL*, the *OWL* spectral sky definition was used in *Lark*. The spectral irradiance was simulated for each desk position with *Lark+D65* and *Lark+OWL*.

The measurements and simulations were collected for daylight conditions under varying sky types and for a period of 10 hours at 6-minute increment over multiple days. The error between the simulation outputs and the measurements was assessed using two metrics: the median relative bias error (MRBE) and the normalized root mean square error (NRMSE), that respectively represent the bias error and the variance error. In addition, the data were assessed visually to detect and analyze any trends under different sky types, times of the day, and potential influence of the window orientation.

3. Results

The simulations were run and compared for a subset of the data. Preliminary results show that the prediction of the spectral irradiance using *Lark+OWL* is relatively accurate. The MRBE for *Lark+D65* and *Lark+OWL* are 13.9% and 14.1% and NRMSE values are 0.36 and 0.39 respectively. The visual assessment of the simulation outputs and measurements suggests that the results accuracy may depend on the time of the day as *Lark+OWL* seems to underestimate the wavelengths between 380 nm to 550 nm and overestimates the wavelengths between 550 nm and 740 nm in the morning and then evens out with the progression of the day.

4. Conclusions

This study tests two approaches to defining a spectral sky model in order to predict spectral irradiance in a building; one utilizing the D65 Illuminant and the other relying on a spectral sky model that accounts for location, weather, and time of the day/year. This last approach relies on the *OWL* tool and strives to address the limitations of the first approach currently implemented in *Lark v2.0*. The simulation outputs of these approaches are compared to real-world measurements of daylight to evaluate the influence of using a spectral sky model on the accuracy of the spectral simulation outputs. Once complete, this comparison study will assess the extent to which a spectral sky model in *Lark* affects the accuracy of spectral simulations compared to spectral measurements.

OP59

PERFORMANCE INVESTIGATION OF CAMERAS USING HDR SENSORS FOR DAYLIGHT GLARE EVALUATIONS

Kim, D.H.[1], Quek, G.[1,2], Wienold, J.[1]
[1] LIPID, École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, SWITZERLAND
[2] Architecture and Sustainable Design, Singapore University of Technology and Design (SUTD), Singapore, SINGAPORE
donghyun.kim@epfl.ch

Abstract

1. Motivation

Luminance distribution measurements, obtained from high-dynamic-range (HDR) imaging technology, are widely applied for indoor and outdoor glare evaluations. One common method is to capture and merge images with *multiple exposures* using DSLR cameras (with RGB sensors) or imaging luminance measurement devices (ILMDs). With this method, users need to be aware that uncertainty remains with using different types of HDR algorithms, moving artifacts, and that pixel saturation can occur.

In recent years, new HDR sensors that can capture an HDR image in a *single exposure* are developed and applied in different fields such as the auto-motive industry. These sensors could potentially reduce uncertainty associated with the multiple exposure method. Since such HDR sensors have a dynamic range of more than 6 orders of magnitude (e.g. 120 dB or 140 dB), this study aims to investigate the performance of such sensors for daylight glare evaluations. Although few studies reported signal characteristics of these sensors in lab test environments, there is a lack of studies applying these sensors in real-world glare studies, especially comparing them to ILMDs as reference.

Therefore, the objectives of this study are: (1) to investigate the pixel-to-luminance signal characteristics of cameras with HDR sensors, then (2) to apply them to various indoor glare scenarios and finally (3) to compare their relative performance with those obtained from the ILMD. This study will also discuss the perspective of these sensors for applying them to typical indoor glare scenarios by addressing the strengths and limitations.

2. Methods

Two different cameras with the following HDR sensors were chosen. The first one is based on logarithmic encoding at the pixel level (CSEM VIP camera with a specified dynamic range of 130 dB) and the second one is based on sub-pixel architecture technology (Lucid TRI054S camera with a dynamic range of 120 dB). Both cameras were equipped with a fisheye lens covering roughly a 180° field of view. We first measure the pixel-to-luminance signal characteristics of both cameras using a spot luminance meter and a LED light source ranging from 1 cd/m^2 to 1 Mcd/m^2 in a dark lab environment. After vignetting corrections were also derived and applied, we then compare relative performance between luminance measurements from these cameras to those obtained from the ILMD (TechnoTeam LMK 98-4) under various electric and daylight conditions (with a varying average of luminance value of the glare sources from 1 kcd/m^2 to 10 Mcd/m^2).

3. Results

For the CSEM VIP camera (10-bit RAW output), a logarithmic behavior of the luminance to pixel-value curve is obtained in a range of 5 cd/m^2 to 100 kcd/m^2. However, above 1 Mcd/m^2, a negative slope of the signal characteristic is observed. This means the output pixel value drops when the luminance increases. As a result, the reverse function (pixel to luminance) is

not unique any more above a level of 30 kcd/m^2, which limits the practical usage of the CSEM VIP camera under certain indoor glare circumstances. Below the critical value of 30 kcd/m^2, the camera was found to have relative differences of less than 10% when compared to the luminance measurements from the Technoteam ILMD.

For the Lucid TRI054S camera (24-bit RAW output), a linear characteristic of the pixel-luminance curve was derived in a luminance range of 1 cd/m^2 to 500 kcd/m^2 and the pixel saturation was observed at a luminance level of around 2.5 Mcd/m^2. We measured various electric and daylight conditions with this camera and will evaluate its relative performance by comparing the luminance images to the ones obtained by the ILMD.

4. Conclusions

In conclusion, the usable dynamic range of the CSEM VIP camera is around two orders of magnitude lower than for typical ILMDs, since the upper limit of its dynamic range was limited due to the observed negative slope signal characteristic at higher luminance levels. This finding was in line with the results from a different research group. In theory, this limitation can be partially solved by using a neutral density filter to increase the maximum level that can be measured reliably. However, considering also the low output signal dynamic (10bit), the uncertainty will increase. Due to the low resolution of the VIP camera sensor (320*240 pixels), a careful approach is needed when researchers use this camera to measure small non-uniform glare sources. Overall, the results suggest that the CSEM VIP camera is a useful glare evaluation device within its reliable luminance range (upper limit of 30 kcd/m^2). In addition, due to its very small size, the camera is especially suitable as wearable glare measurement device.

For the Lucid TRI054S camera, the results suggest that the device has a high potential to be applied in both indoor and outdoor glare scenarios as the image sensor has high resolution (2880*1860 pixels) and the upper limit of luminance measured is around 2 Mcd/m^2. Results on the performance investigation of this camera for very high luminance values (>10M cd/m^2) using an additional ND filter (ND2.000 from Midwest Optical Systems) will also be discussed in the paper.

Session PA6-1
D3/D4 - Energy efficiency

Wednesday, September 20, 10:00–11:20

OP2

A MACHINE-LEARNING-AIDED APPROACH TO IMPROVE OCCUPANCY-BASED LIGHTING CONTROL SYSTEMS

Bian, W.K.[1], Hu, W.Y.[1]
[1] School of Architecture, Design and Planning, The University of Sydney, Sydney, AUSTRALIA
wenye.hu@sydney.edu.au

Abstract

1. Motivation, specific objective

Occupancy-based lighting control is a widely used technique to reduce electrical energy consumption in lighting systems. This technique relies on occupancy sensors that detect areas where occupants are present, and illumination is required. The signals from these sensors are collected and processed by a controller, which then adjusts each light source according to pre-set dimming parameters. However, there is no established method to guarantee that similar visual environments are maintained when some luminaires are dimmed or turned off. Traditional lighting parameters, such as average illuminance, illuminance uniformity and luminance, are unable to be assessed in real-time in an occupancy-based lighting system, which may lead to negative effects on occupants' visual comfort, perception of safety, etc.

Therefore, in this study, an innovative machine-learning-aided approach that provides real-time optimal dimming levels, was proposed to minimise energy consumption and maintain desired illuminance, uniformity and luminance for any occupied areas. This approach is designed to address the shortcomings of traditional occupancy-based lighting systems and ensure that occupants can work or reside comfortably in a safe and visually consistent environment.

2. Methods

This proposed approach consists of four steps: 1) Illumination determination: The desired illuminated locations (i.e task areas), their boundaries, and the required average illuminance, target luminance and uniformity are identified. 2) Simulation data collection: Each light source's dimming level is assigned using Monte Carlo methods, and the illuminance, luminance and uniformity of the desired target areas are calculated using Radiance, a validated lighting simulation software. 3) Neural network training: The database created in Step 2 is used to train neural networks and generate corresponding computational functions which can rapidly calculate illuminance, uniformity and luminance for any given dimming levels. 4) Optimization: The computational function is used to optimize the dimming levels to find the optimal energy-saving solution that simultaneously satisfies all requirements of lighting parameters that were set in the first step.

A series of computational simulations have been undertaken to evaluate the feasibility of the proposed methods. Specifically, the simulations involve the installation of 16 downlights with 60-degree beam angles on the ceiling of a square room measuring 7 m × 7 m × 3 m. The dimming levels of the downlights are optimized and adjusted to achieve an average illuminance of 320 lx, with a minimum-to-average uniformity ratio of at least 0.7 across any desired illuminated field on the horizontal working plane of 0.7 m or vertical wall. The size of the illuminated field varies between 50° and 100° in 10° increments, depending on the visual angle. The number of illuminated fields, which corresponds to the number of occupants, ranges from one to five in accordance with the recommended net floor area per person for offices, workrooms, and residential living areas, which is 10 m^2/person. The final optimisation results are validated using the AGI32 software.

3. Results

Technical parameters in Radiance were validated by a comprehensive comparison conducted between lighting simulations in Radiance and AGI 32. The results demonstrated that for the same lighting scene, the average illuminance difference of the lighting target was no greater than 2 %, and the uniformity difference was no greater than 1%.

A Bayesian model was used for the neural network training process in MATLAB. To achieve relatively accurate training, it was found that a dataset of at least 100 times the number of lamps was required. With a dataset of this size, the trained computational functions provided illuminance, luminance, and uniformity results that closely matched those simulated in Radiance. The difference in average illuminance and luminance was less than 1 % and the difference in uniformity was less than 0.05%.

A genetic algorithm was further implemented in MATLAB to determine the optimal dimming levels for each luminaire quickly in scenarios that involved various random locations and sizes of task areas, as well as a random number of occupants. The resulting dimming levels can always guarantee the desired illuminance, luminance and uniformity. In comparison to the conventional uniformly distributed lighting strategy, the energy consumed by the proposed lighting systems can be reduced by up to 85.2%.

The proposed approach has been proven to be highly effective in determining optimal dimming levels in a timely manner, regardless of the location, size, or number of task areas. The accuracy of the proposed approach was assessed by five scenes with multiple random task areas. The specific dimming levels for each luminaire determined using this approach were then used to create replicated scenes in AGI32 for comparison purposes. The results indicated that the difference in average illuminance, uniformity, and luminance between AGI32 and the proposed approach were within 1%.

4. Conclusions

The proposed machine-learning aided approach offers a promising solution to quickly optimize dimming levels for any desired area, at any location (either horizontal or vertical), while maintaining the desired visual experience and minimizing energy consumption. The response time is fast enough to provide real-time optimal dimming levels based on the signals from occupancy sensors. Validation of the AGI32 software confirms the availability and accuracy of the proposed approach. In the future, this technique has the potential to enhance conventional occupancy-based lighting strategies and transform them into gaze-dependent lighting, provided that gaze direction can be accurately detected in real-time.

To ensure a balance between visual needs and energy conservation, future research will quantify the relationship between the illuminated field size and task performance as well as psychological impacts on occupants. This research will contribute to the development of lighting control systems that are not only energy-efficient but also capable of providing the optimal visual experiences for building occupants.

OP45

A MODEL FOR DETECTING DAYLIGHT PROVISION TO SAVE ENERGY AND TO COMPLY WITH THE EN-12464-1 STANDARD

Einola, K.A.[1], Juslén, H.[2]
[1] Aalto University, Espoo, FINLAND, [2] Helvar Oy Ab, Espoo, FINLAND
kiia.einola@aalto.fi

Abstract

1. Motivation, specific objective

Daylight-linked control (DLC) has been given increasing attention due to its energy-saving potential. DLC aims to maintain a predefined illuminance level throughout the day by dimming lights when enough daylight is available. The required minimum maintained illuminance level ($\bar{E}_m$) of 500 lx for many office areas is determined in the indoor lighting standard EN-12464-1. However, according to the revised standard $\bar{E}_m$ should be increased under specific 'context modifiers', for example, when visual work is critical, the task area or activity area has a low daylight provision, the visual capacity of the worker is below normal, or the task is undertaken for unusually long time. In the standard, the modified $\bar{E}_m$ is increased in steps according to the scale of illuminance. For example, the needed one-step increase would be 250 lx for low daylight provision.

As mentioned, one of the context modifiers requires that $\bar{E}_m$ should be increased if the task area or activity area has a low daylight provision. Knowing whether the daylight provision is low, is trivial in windowless rooms, but it gets more complicated when at least some natural light is available. For example, daylight availability in northern countries during winter and summer has significant variations. Nevertheless, maintaining increased $\bar{E}_m$ always does not make sense from the energy-saving perspective. Therefore, it would be important to know when the daylight provision is at a sufficient level to lower the $\bar{E}_m$.

This study aimed to determine if a smart lighting system with photosensors could provide parameters to detect daylight provision levels automatically. By being able to lower the overall $\bar{E}_m$, energy could be saved. The research questions were: RQ1: Could the indoor ambient light sensors automatically detect sufficient daylight in the presence of artificial light? RQ2: How much energy could be saved by lowering the maintained illuminance when the daylight provision is interpreted high? This study adds to the literature on DLC, as it has typically been studied without considering the requirement of the EN-12464-1 for increased maintained illuminance in the absence of sufficient daylight.

2. Methods

This study was accomplished by measuring daylight availability in different rooms with and without artificial lighting. Ambient light sensors were used, and they were placed on the ceiling in a grid. Moreover, motion sensors were used to determine if someone was in the room during the measurement period, which would turn on the luminaires. The measurements were primarily conducted during weekends to avoid people affecting them. Data was collected in southern Finland in autumn 2022 and winter and spring 2023.

There were 25 measurement periods that took place in three different rooms. Two were smaller offices with east-facing windows, and one was a larger open office with east, south, and west windows. Due to the number of sensors, the measurements were done only one place at a time. Additionally, the sensors were tested in laboratory circumstances.

Data was analysed using Python to determine if parameters such as average or variance would indicate high daylight provision and if it could be separated from the artificial light provision. All sensors were marked with an address, and their precise locations were known. In addition, weather data from Finnish Meteorological Institute was used in order to understand the weather conditions. However, the granularity of the weather data was

insufficient to detect minor differences, such as if the weather was cloudy or only partly cloudy during the measurement period.

3. Results

It was possible to create a model that separates artificial and natural light from ambient light sensor data. This information could be used to lower the $\bar{E}_m$ during high daylight provision. Artificial light prevented the usage of average illuminance, but the shape of the measured light curve could be used to detect daylight provision levels.

The modified $\bar{E}_m$ in case of low daylight provision is 50% higher than the minimum $\bar{E}_m$, which indicates that a significant amount of energy could be saved while still satisfying the users' needs. Generally, the daylight provision was lower during the winter than at other times of the year, but some days did not follow this pattern. Therefore, the authors suggest that higher illuminance would be maintained during dark seasons and when light sensors detect less daylight, such as cloudy days. These findings could be used to develop DLC even by considering the context modifiers in the EN-12464-1 standard.

4. Conclusions

This study suggests that light sensor data could be used to comply with the EN-12464-1 standard requirement to increase the maintained illuminance according to daylight provision while still saving energy. At times of high daylight provision, the overall $\bar{E}_m$ could be decreased. This approach differed from the conventional DLC logic, where a constant illuminance is maintained throughout the day.

According to the measurements, the days with increased daylight provision were mainly during late spring and early autumn, but there were some exceptions. Moreover, the increased daylight provision does not always mean that it could be utilised. For example, daylight provision could be high during winter, but the low sun angle makes it difficult to utilize without glare. Therefore, maintaining modified $\bar{E}_m$ is suggested in northern countries during that time even though some days have increased daylight provision. A narrow selection of room types limited this study. Therefore, further studies should be conducted with different spaces (i.e., several floors and window directions) and locations.

OP58

ANALYSES ON LIGHTING ENERGY CONSUMPTION THROUGH COST-OPTIMAL INVESTMENTS FOR RESIDENCES: A CASE STUDY IN TURKEY

Kaymaz, E.[1], Manav, B.[2]
[1] Department of Architecture, Bursa Uludag University, Bursa, TURKEY**,** [2] Department of Interior Architecture and Environmental Design, Kadir Has University, İstanbul, TURKEY
ekaymaz@uludag.edu.tr

Abstract

1. Motivation, specific objective

Residences among the building stock accounts for nearly 20% of the total energy consumption, according to the energy policy review which is published in 2021 by the International Energy Agency (IEA) in Turkey. Energy consumption in residential sector has increased by 12% between 2008 and 2018, due to the rapidly growing and transforming building stock driven by the population growth and urbanization. Therefore, energy efficiency in residences has a significant impact on Turkey's economy which is heavily dependent on importing fossil fuels. To set a strategy to improve energy efficiency and reduce greenhouse gas emissions a framework for calculating cost-optimal levels of passive design strategies shall be studied which is also subject to this study. We aimed to propose an approach to enhance lighting energy performance of a residential building through building energy simulation (BES) based on optimization method.

Building orientation and openings can be considered as one of the most important passive design parameters influencing the energy performance of buildings and indoor daylight availability. The geometry, optical and thermo-physical properties and orientation of windows determine solar gains, heat loss and daylight intake from the building envelope. The challenge to balance trade-offs among competing the goals of lighting, heating, and cooling energy demand, thermal and visual comfort, and the cost of improvement measures has been widely observed using building performance optimization methods. In this research, the performance of the architectural design elements is discussed in the context of annual lighting energy consumption, operational carbon emission and global cost. Design variables including façade orientation (-90°/+90° in intervals of 5°), window size (1,00m, 1,50m, 2,00m, 2,50m), window-to-wall ratio (WWR rate ranges from 30% to 50% in intervals of 5%), thermo-physical properties of glazing (10 options for clear and low-emissivity glazing) and light reflectance value (LRV) of walls (ρ:0,5, ρ:0,6, ρ:0,7, ρ:0,8) are investigated for a case study located in temperate-humid (Bursa) and hot-dry (Diyarbakır) climate zones in Turkey. Daylight performance of the residential units is also predicted by the climate-based daylight modelling (CBDM).

2. Methods

The development of the methodology is presented through the following steps;

i) Interior lighting system proposal for the case study,

ii) Lighting energy simulations of the reference building and design options,

iii) Sensitivity analysis to define the impact of the design variables on lighting energy consumption, operational energy cost, carbon emission and payback period of the investment.

iv) Optimization analysis to accomplish best performing design solutions in terms of annual lighting energy using Genetic Algorithms (GAs).

v) Global cost analysis of optimal solutions

vi) Comparative daylight analysis for the residential spaces of the best solutions using dynamic daylight performance measures.

The lighting system is modelled in DIALux Evo program. The reference building energy model is generated by Designbuilder in accordance with the project details and information in energy performance certificate (EPC). Lighting power densities are determined according to the lighting scenario. The passive design options annual lighting energy is compared with the base case through a series of parametric simulations in EnergyPlus engine. The operational energy costs, carbon emissions and pay-back period of the investments are calculated in Excel using electricity unit price and CO_2 conversion factor. Initial investment, labour, transportation costs and lifespan of glazing products are determined according to economic indicators, data obtained from market research and unit prices published by the government. Options with higher lighting energy costs or longer payback periods than the lifetime of the reference building are eliminated by sensitivity analysis. Optimization analysis is carried out in DesignBuilder using GAs which allows us to identify the optimal solutions in the design space that best meet the research objective by running about 2500 simulations for each climate zone. The global cost calculations including initial investment, running, replacement and energy costs are done according to Energy Performance of Buildings Directive (EPBD) frame work and economic evaluation procedure EN 15459-1:2017 for the base case and optimal solutions for 30-year calculation period. Finally, annual daylight assessment of optimal solutions is performed by CBDM metrics including UDI (Useful Daylight Illuminance), ASE (Annual Sunlight Exposure), sDA (Spatial Daylight Autonomy) using DesignBuilder interface and Radiance daylighting engine.

3. Results

The optimization analysis includes 59.2000 total possible design solutions by the combination of 62 options within 6 design variables. The lighting energy-oriented, well-balanced, and cost-oriented solutions are selected as the most optimal conditions in terms of their advantages over the remaining solutions. Compared to the reference building, we achieved savings of 40,3% on lighting energy (9,4 kWh/m^2a), 18,8% of global costs (362 €/m^2a), as well as a reduction of 11,6% on operational carbon emissions (3,8 $kg.CO_2$ eq/m^2a) for the lighting energy-oriented solution. Daylight performance of the best variable combinations will be presented. Heating and cooling energy consumption will also be taken into account for an integrative building design approach. Results of annual energy consumption of the HVAC system will be compared to the optimum building solutions for temperate-humid and hot-dry climates.

4. Conclusions

The research aimed at providing a framework for the impacts of façade orientation, building envelope and LRV of walls on lighting energy performance which are assessed through a simulation-based optimisation study. More specifically, the result of lighting energy analysis is then compared with the daylight performance of the case study units by the climate-based daylight modelling (CBDM). The findings of this study are believed to be useful to improve the energy efficiency of future residential projects with the goal to enhance visual comfort, reduce lighting energy and global costs associated with architectural and interior design.

OP71

ENERGY SAVINGS FOR ADAPTIVE LED CONVERSION IN EXISTING ROAD LIGHTING INSTALLATIONS

Onaygil, S.[1], Guler, O.[1], Yurtseven, M.B.[1], Avsar, T.B.[2], Buyukbas, B.[2]
[1] Istanbul Technical University, Energy Institute, Istanbul, TURKIYE
[2] YEDAS, Mimar Sinan Mah. 110. Sok. No:1, Atakum, Samsun, TURKIYE
onaygil@itu.edu.tr

Abstract

1. Motivation, specific objective

The difficulties faced by countries in energy supply have made "energy efficiency" a priority in national energy policies for years. In recent years, the results of the Russia-Ukraine war are considered an energy crisis, especially for European countries dependent on foreign energy. With these pressures, superficial applications are also carried out in the lighting in public outdoor areas without paying much attention to the differences between energy efficiency and energy saving. Therefore, more than ever, there is a need for cost-effective good implementations that save energy, taking into account the current international lighting standards and recommendations. Since the beginning of 2000, within the scope of energy efficiency studies, new installations are generally given priority in LED conversions in road lighting. However, the energy-saving values to be achieved by improving the existing road lighting installations are very high. In addition to this, in recent years, it has been announced that the energy-saving potential in installations where LED conversion can be integrated with adaptive systems will also be high. In order for policymakers and decision-makers to determine the right strategies for road lighting, there is a need for good practices where the energy-saving values to be obtained can be seen clearly and reliably.

In this study, evaluating the data of one of the three pilot road applications carried out within the scope of the Energy Market Regulatory Authority supported project carried out to strengthen the information infrastructure of Electricity Distribution Companies, which are defined as the implementing actors in LED conversion in Turkey, it is aimed to determine the energy saving values to be obtained as a result of the integration of LED conversion and adaptive systems in existing road lighting installations and to examine the applicability of the projects.

2. Methods

- A road with M2 lighting class, currently illuminated by high pressure sodium lamp (HPSL) luminaires, has been chosen as a pilot in the province of Samsun in the north of Turkey.
- The LED conversion was carried out in the existing lighting installation, only by changing the luminaire.
- The luminaires on the pilot road were replaced with new HPSL luminaires so that comparisons could be made properly.
- Lighting design calculations were made with the catalogue data and laboratory measurements of new HPSL luminaires.
- Field measurements were carried out on the pilot road where new HPSL luminaires were installed.
- Road surface reflectance class were examined with the design and field measurement results.
- An automation scenario was created in which M2, M3 and M4 lighting classes are satisfied at different times with literature/standard recommendations and vehicle density information based on observations on the pilot road.
- Lighting design calculations have been made for the LED installation where M2, M3 and M4 lighting classes will be provided.

- HPSL luminaires on the pilot road were removed and replaced with LED luminaires and an automation system including vehicle counting sensors was installed.
- The dim levels at which M2, M3 and M4 lighting classes are satisfied were determined by field measurements and programmed to the system.
- The validity of the automation scenario created during the design phase was examined with the vehicle density data obtained from the field.
- The lighting quality values measured after the LED conversion were compared with the HPSL installation values before the conversion. Values were normalized in $W/m^2.cd/m^2$ unit and energy saving rate were determined according to different luminaire efficacies.
- By determining the usage times of road lighting at M2, M3 and M4 levels according to the sunset and sunrise times, the additional energy saving rate obtained with the adaptive system on the pilot road was determined.
- In the existing lighting installation, cost-benefit analyses were made for the non-automated and automated situation in the LED conversion, which is carried out only with the replacement of luminaires, and the return on investment was calculated.

3. Results

With the design, implementation, field measurements and data analysis carried out on the pilot road It has been concluded that;
- In existing road lighting installations, it is appropriate to take the road surface reflectance class R1 instead of R3,
- According to the prior vehicle count data obtained from the field, the automation scenario created during the design phase is compatible with the real conditions,
- Energy savings of 63.8% can be achieved by converting the installation with HPSL to LED,
- Additional 33.3% savings can be achieved with the integration of the automation system with three lighting levels.

In addition, the payback period of the non-automated LED conversion investment is calculated as 0.88 years; the automated one is calculated as 2.9 years.

4. Conclusions

In LED conversion, priority should be given not only to new installations, but also to existing road lighting installations with high energy saving potential. With appropriate design calculations and production technologies, LED and adaptive applications in accordance with the standards can be realized only as a result of changing luminaires in existing installations. These applications, which can achieve significant energy saving values throughout the country, are also cost-effective projects.

Session PA6-2

D4/D6/D8/D1 - Metrology challenges and opportunities

Wednesday, September 20, 10:00–11:20

OP29

IS IT TIME FOR A NON-BIOLOGICAL REFERENCE OBSERVER?

Iacomussi P.[1,7], Braun A.[2,7], Carlson P.[3], Deegan B.[4,7], Denny P.[5,7], Dingess R.[6]
[1] INRIM, Torino, ITALY, [2] Technical University of Dusseldorf, Dusseldorf, GERMANY, [3] Automated Roads, Greensboro, USA, [4] University of Galway, Galway, IRELAND, [5] University of Limerick, Limerick, IRELAND, [6] Mercer Strategic Alliance, Mount Olive, USA, [7] IEEE P2020 normative group
p.iacomussi@inrim.it

Abstract

The CIE system of physical photometry is based on the CIE standard photometric observer (ILV 17-21-036) *"an ideal observer having a relative spectral responsivity curve that conforms to the spectral luminous efficiency function for photopic vision",* whose foundations were laid in 1924, on scotopic vision. Subsequently over the years new reference observers were introduced like the CIE reference observers for colorimetry (1931 and 1964) or the 10° observer (1964) and so on.

These observers represent the basis of all light related measurements when the measurement focus is the understanding of the actions of lit environments on human observers or to test the metrological performances of instruments for light measurements (e.g. f_1' parameter).

Just like observers, CIE established also geometric reference conditions for measurements, strictly related to the application field and lighting condition like for colorimetry (e.g., geometry 0/45 and CIE reference illuminant D65). For road applications, CIE defined reference geometrical conditions figuring the CIE standard photometric observer as an ideal road user, usually a driver, observing the road from assigned points of view. Namely, for road lighting (luminance measurements and design), the eyes are at 1,5 m from the ground and the angle of observation is 1° (road surface luminance coefficient measurement too), while for road marking measurements, the eyes are at 1,2 m and the angle of observation is 2,29°. The two conditions of observation imply a viewing distance of 85,9 m and 37,5 m, respectively.

These conditions are predicated on the assumption that driving on a road is a visual task (for a human driver) of sensing the road environment and act consequently. Standards state the requirements of all related road elements (lighting, active/passive signalling, vehicles) to ensure safety by guarantee their correct perception and recognition by the CIE standard photometric observer driver to trigger appropriated (corrective) actions within a standardized (human) response time.

The CIE definition of reference conditions and reference observers and subsequent standardization of performances didn't stop the market nor the developments of new sensors and measuring systems, lighting systems, signalling devices and materials. Instead, it ensured a safer road environment, accurate characterizations, and the development of related detector Key Performance Indicators (KPI) like those described in CIE TR 231:2019 "CIE classification system of Illuminance and luminance meters" which are useful for metrological performances comparison and improvement of accuracy and signalling devices performances.

Considering the present and future technological trends and knowledge of visual performance and road environment characterization, the above reference conditions and reference observer are no longer appropriate, especially because driving is no longer an only human visual task.

Advanced Driver Assistance Systems (ADAS) play a relevant role in compensating for human physical limitations and in increasing road safety. Cameras and sensors (e.g., lidar) are crucial for a vehicle to sense and perceive road surroundings, and to date there has not been a consistent and standardized approach to measure sensors quality and performances for the specific application of increasing safety of the driving act.

The IEEE P2020 group provided a new standard with a list and description of KPI and reference conditions for testing image cameras quality performance for easy market comparison also in ADAS related applications. But, since reference conditions or minimum reference performances are not defined in a dedicated standard, a functional and metrological comparison of ADAS performance is still difficult.

The paper describes the needs of a non-biological reference observer and new reference conditions for road applications and proposes a CIE activity on the subject. Having these new bases, it will be possible to transform the road safety by combining current regulatory requirements for human, based on old and under discussion models and conditions (i.e. Adrian model, CIE reference r-tables, …) and limited by constraints of human visual systems (logarithmic response) with new non-bio performance related requirements especially for road elements (i.e. active and passive signalling) pushing the market to introduce new solutions. Currently, ADAS assist the driver sensing the environment but bend their capabilities to human visual standard requirements limiting their potentialities because additional non-biological requirements are not defined.

The paper provides a first ontology description and introduces the most relevant characteristics like being not $V(\lambda)$ based, with detection performances expressed in terms of probability functions also. The paper also investigates the impact on performances of material road related starting from road surface and road markings characteristics and measuring conditions.

OP39

THE NEED FOR STANDARDISATION IN THE MANUFACTURE, CALIBRATION AND USE OF BILIRUBIN RADIOMETERS

Bergen, A.S.J.[1], Lynn, M.P.[2]
[1] Australian Photometry and Radiometry Laboratory, Melbourne, Australia
[2] Retired ultrasound and non-ionising radiation specialist, Axminster, Devon, UK
tony@aprlab.com.au

Abstract

1. Motivation, specific objective

Jaundice (hyperbilirubinaemia) is a condition in which the skin turns a yellowish colour due to the presence in the blood of high levels of bilirubin, an orange-coloured pigment contained in red blood cells that is released into the bloodstream when the cells break down. It is relatively common in prematurely delivered new-born babies because the baby's liver hasn't developed sufficiently to remove the bilirubin from the bloodstream. If untreated it can lead to bilirubin encephalopathy and brain damage. Treatment is usually by phototherapy: exposing the skin of the baby to blue-coloured light in the wavelength range near the peak of the bilirubin action spectrum around 450 nm to 460 nm.

Bilirubin radiometers measure the broadband irradiance of the phototherapy lamps used in the treatment, to ensure that adequate levels of irradiation are used. Strictly speaking, "bilirubin radiometer" is an incorrect term since the radiometer is measuring the radiation used to break down the bilirubin, rather than the bilirubin content itself, but "bilirubin radiometer" is a convenient common expression.

There are two main problems with the calibration and use of bilirubin radiometers.

1. There is no standardised optical radiation source for the treatment, and no standardised spectral responsivity function for the instruments. This can lead to significant spectral mismatch errors when using an instrument to measure a source that has a different spectral distribution to the source used in the calibration.

2. The instruments themselves often display measurements in the units of spectral irradiance ($\mu W.cm^{-2}.nm^{-1}$) rather than broadband irradiance ($\mu W.cm^{-2}$). This doesn't make sense, since the instruments are integrating over a wavelength range – reporting the result as a spectral quantity is just like saying that the distance between Melbourne and Sydney is 100 km/h! Furthermore, it requires the calibration lab to make a judgement on the bandwidth of the instrument.

2. Methods

The author's laboratory has begun a series of intercomparisons with other laboratories in the calibration of bilirubin radiometers. The intention of the intercomparisons is to gauge the range of errors that can be encountered if the intercomparison is not properly controlled, and to gauge how good an intercomparison can be achieved if the variables are controlled properly. The first instrument used is one that properly indicates readings in broadband irradiance ($\mu W.cm^{-2}$). A future intercomparison will use an instrument that is reporting in the spectral quantity ($\mu W.cm^{-2}.nm^{-1}$) and also requires the laboratories to make a judgement on the bandwidth of the instrument.

3. Results

The results so far indicate exactly the problem highlighted in the first point above. For the first intercomparison the sources used were initially not controlled. One laboratory used a source which had a narrow-band filter with a bandwidth of 10 nm and centre wavelength of approximately 458 nm whereas the other laboratory used an LED source with FWHM of 20 nm and centroid of 450 nm. The difference in calibration results exceeded 15 % (E_n = -2.7). The

intercomparison was then repeated with the first lab using an LED source very similar to the second lab. The difference in calibration results then reduced to 1.5 % (E_n = -0.24).

An intercomparison is being initiated with a third laboratory and the results are expected to be available in June 2023.

4. Conclusions

The results of the intercomparison emphasise the need to effectively communicate the nature of the source that the instrument will be used to measure, so that the calibration can be made fit-for-purpose. Unfortunately, not all applicants know this, and indeed there is often a layer of administration between the users of the instrument and the calibration laboratory which make it even harder for the laboratory to communicate with the user.

It also emphasises the need for coordination between the instrument manufacturers, calibration laboratories and the users of the instruments to come to a common understanding of the manufacture, calibration and use of the instruments. Once this is achieved it may then be possible to provide standardisation – future work for CIE Division 2.

OP33

HDR IMAGING FOR LOW LIGHT HYPERSPECTRAL ACQUISITION

Raza, A., Jost, S., Dumortier, D.
Univ Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR5513, 69518 Vaulx-en-Velin, FRANCE
aiman.raza@entpe.fr

Abstract

1. Motivation

Hyper-Spectral Imaging (HSI) combines conventional imaging sensors with spectroscopy and provides image data containing spatial and spectral information. For each pixel of the image, the spectral power distribution (SPD) is measured to generate datasets with three dimensions (row, column, and corresponding spectral information per wavelength). Recently, hyperspectral cameras have seen a fast development with the availability of high spectral/spatial resolution devices on the market. Though, the accuracy of hyperspectral data reduces significantly under low light conditions (<100 cd/m²).

High-Dynamic Range (HDR) imaging offers the possibility to accurately capture the dark pixels as well as bright pixels by combining images with different exposure values. This technique can be extended to hyperspectral images also by taking hyperspectral captures at varying exposure levels to accurately obtain the spectral information for every pixel, dark as well as bright, for low-lit environments.

2. Material and method

A Specim FX10 push broom hyperspectral camera was used to establish a generalized protocol. A JETI Specbos 1211-UV spectroradiometer was used to measure the reference spectral radiance. Two measurement scenes, each containing a Macbeth Colour Checker Chart (MCC) were chosen for testing. A light-booth with low-light (max luminance 115 cd/m², LED lamp, CCT=2800K, Ra=82); and a low-lit reduced-scale model of an automobile tunnel (max luminance 35 cd/m², LED lamp, CCT=5000K, Ra=85).

HDR imaging requires captures at varying Exposure Values (EVs) to capture every possible pixel accurately. Hyperspectral imaging requires scanning and capturing the spectral information for each pixel for one target wavelength at a time. Merging the two imaging techniques together add up complications that require pre-defining a streamlined process. The process involves identifying a middle EV and two or more other EVs, higher and lower than the middle EV, and then capturing the spectral data for each EV.

The raw spectral data obtained for each EV can be fused together to create a single hyperspectral image containing spectral information for each properly exposed pixel. To identify the EV that properly exposes a pixel, we need to identify the upper and lower limits of the hyperspectral imaging system which lead to over exposed or under exposed data.

To identify the raw radiance values of the HSI device that over/under expose the camera optics, hyperspectral captures were done under an equi-energy light source with increasing exposures of 5-10-20-40-80 ms. The captures were done in dark (0 cd/m², camera lid on) to identify noise and at 2791 cd/m² to identify saturation (measured on Spectralon). These measurements helped us in identifying:

a) The raw radiance value which corresponds to over-exposure. Over-exposure is characterized by flat signals (3438 raw radiance units).

b) The raw radiance value which corresponds to under-exposure. Under-exposure is characterized by unstable raw radiances with values comparable to noise (1,58 raw radiance units).

With the upper and lower limits of raw radiance values for properly exposed pixels, the spectral data obtained via different EVs can be merged to obtain a single spectral image of properly exposed pixels. The merging technique could be: (i) identifying the first radiance value that falls within the limits of the camera and discarding the spectral data from other EVs (HDR-First method); (ii) identifying all the radiance values that fall within the limits of proper exposure and storing a mean (HDR-Mean) or median (HDR-Median) radiance value per pixel.

Either of the merged HDR hyperspectral output requires further calibration to produce radiances in SI units. To calibrate the hyperspectral camera, captures were taken in a light booth covered with a white cloth of a uniform reflectance, lit by a bright-cold incandescent source, containing MCC and a Spectralon white standard. The raw hyperspectral data associated with the Spectralon was extracted from the uncalibrated output file and divided with the corresponding reference spectral radiance measured in the same geometry with the spectroradiometer to obtain the calibration curve.

3. Results

After obtaining the calibrated HDR hyperspectral images for the different merging methods, comparisons were done on the 24 MCC patches to identify the method that produces the most accurate spectral image (for radiometric-photometric-colorimetric accuracy and image quality). Assessments were also done to compare the HSI-HDR data with HSI data obtained from a single optimum EV (HSI-SEV).

Radiometric comparisons were done using the Normalised-Root-Mean-Square-Deviation scores between the spectral data. Photometric comparisons were done using Mean-Absolute-Percentage-Error between the luminance values. Colorimetric comparisons were done using the DeltaE*00 values. Images were evaluated with the Naturalness-Image-Quality-Evaluator (NIQE). A two-way ANOVA was conducted on the data for statistical significance.

For the low-lit light booth, radiometrically and photometrically, a significant improvement was identified for the HDR-First method. Colorimetrically, the Delta E*00 values for the low-lit light booth data were significantly better for HSI-SEV (=middle EV) method. The tunnel was similarly reproduced for all the methods (HSI-HDR or HSI-SEV).

In terms of image quality, for either of the scenes, HDR-Mean and HDR-Median methods produced the best quality images (visually and also as per the NIQE scores).

4. Conclusions

Hyperspectral imaging provides a non-invasive method to analyse the spectral, photometric and colour content of a complex scene through a single capture. Though, low-lit environments are prone to a reduction in accuracy due to increased noise. Extending the HDR imaging technique to hyperspectral imaging has demonstrated a significant improvement in the radiometric/photometric data and image quality for low-lit light-booth scene. For the tunnel, no impact is observed for the use of HSI-HDR method. This could be due to the too close horizontal positioning of the Macbeth chart on the floor of the tunnel, maximising the noisy data. This is further corroborated by the fact that the 2D images obtained using the HDR-Mean and HDR-Median methods were significantly of a better quality. A slightly tilted vertical positioning of the MCC could improve data acquisition.

The colorimetric errors were increased with the use of HSI-HDR methods. Perhaps, the use of a biased HDR bracketing could resolve this issue where only EVs higher than the central EV are selected instead of higher and lower EVs. Overall, the use of HSI-HDR techniques show a promising improvement for low-light hyperspectral imaging.

OP72

LI-FI DATA TRANSMISSION PERSPECTIVE IN HUMAN ARTIFICIAL VISION IN BLIND PATIENTS

Or, K.H.[1,2]
[1] Private Office of Ophthalmology, Istanbul, TURKEY, [2] Private Office of Ophthalmology, Hamburg, GERMANY
hilmi.or@gmail.com

1. Motivation, specific objective

In many of the techniques for artificial vision with intraocular implants in almost blind humans digital data (which are then converted to electrical data/impulses) has to be transmitted to the retina. For that reason wires are implanted from the outside of the eye across the eye to the retina. On the other hand Li-Fi (Light Fidelity) is the name of a technology for wireless data transmission using visible light or infrared radiation. The use of LiFi may enhance the transmission of lighting data from environment to the retina without using wires.

2. Methods

Techniques of conventional retinal chip implant surgery for in blind people with wires are compared with possible Li-Fi transmission of illumination data without wires.

3. Results

LED light source(s) may be fixed in the glasses worn by the blind patient, which transmit the illumination data from environment to the chip or sensor in the eye. Compared to other wireless communication (like WiFi) standards, Li-Fi has significant advantages like fast wireless data transmission, real-time communication, no interference with other sources of the need for line of sight. Another advantage is that the wavelengths used in Li-Fi are physiologic for the eye tissues.

4. Conclusions

Li-Fi use may be a good alternative for eye sensor/chip implants for artificial vision in blind humans.

Session PA7-1
D2/D6 - Integrative lighting 3

Wednesday, September 20, 12:30–14:05

OP20

GUIDELINES AND CHECKLIST FOR DOCUMENTING AND REPORTING HUMAN LABORATORY-BASED OCULAR LIGHT EXPOSURE INTERVENTIONS

Manuel Spitschan[1,2], Laura Kervezee[3], Renske Lok[4], Elise McGlashan[5], Raymond Najjar[6]
[1] Max Planck Institute for Biological Cybernetics, Tuebingen, GERMANY, [2] Technical University of Munich, Munich, GERMANY, [3] Leiden University Medical Center, Leiden, NETHERLANDS, [4] Stanford University, Stanford, USA, [5] Monash University, Melbourne, AUSTRALIA, [6] National University of Singapore, Singapore, SINGAPORE
manuel.spitschan@tum.de

Abstract

1. Motivation, specific objective

The wide-reaching effects of light on human health and wellbeing have been highlighted by a variety of basic laboratory findings. However, to date there is no consensus on how light characteristics in such studies are reported. The goal of this project was to develop a specific reporting checklist and guidelines for light characteristics in laboratory-based investigations on the impact of light on non-visual physiology.

2. Methods

We conducted a four-step Delphi process involving international researchers to establish consensus on the importance of concepts and quantities that can be used to describe experimental light interventions as well as the best practices on the format and specification of these items. This process involved three questionnaire-based feedback rounds and one face-to-face group discussion. Efforts were made to invite a group of participants that is representative with respect to gender, geographical location, and seniority. The project was registered on the EQUATOR Network.

3. Results

The resulting guidelines and checklist contain a variety of reporting items, spanning protocol-level characteristics (description of experimental setting, timeline of experiment, pre-laboratory sleep-wake/rest-activity behaviour, pre-laboratory light exposure, immediate prior light exposure), measurement-level characteristics (measurement plane, viewpoint and location, type, make and manufacturer of the measurement instrument, calibration status of the instrument), participant-level characteristics (ocular health, pupil size, relative time), light source types (type, make and manufacturer of the light source, use of wearable filtering apparatus), light-level characteristics (illuminance/luminance, spectral irradiance/radiance distribution, α-opic irradiance and/or radiance, α-opic equivalent daylight illuminance and/or luminance), colour characteristics (peak wavelength and bandwidth, colour appearance quantities, colour rendering metrics), and temporal and spatial characteristics (location of stimulus and viewing distance, temporal pattern, relative or absolute size of the stimulus). The checklist is available as a fillable PDF.

4. Conclusions

We present the first international consensus checklist and guidelines for reporting light level characteristics in intervention studies. The checklist and guidelines will facilitate the transparent and reproducible reporting of interventions. We are currently seeking endorsement from a range of scientific societies.

OP19

PHYSIOLOGICALLY-RELEVANT SPECTRAL AND ALPHA-OPIC CHARACTERISATION OF NATURAL SCENES ACROSS TIME AND SPACE

Niloufar Tabandeh[1,2], Alexander Hahn[1,2], Manuel Spitschan[1,2]
[1] Max Planck Institute for Biological Cybernetics, Tübingen, GERMANY, [2] Technical University of Munich, Munich, GERMANY
niloufar.tabandehsaravi@tuebingen.mpg.de

Abstract

1. Motivation, specific objective

The world around us is complex in its visual attributes, differing in spectrum, intensity, colour, spatial make-up and temporal properties. Natural scenes have long been known to be statistically regular, and several publicly available data sets use calibrated or uncalibrated sensors to analyse these statistical regularities. However, no dataset currently captures the spectral, spatial and temporal properties of natural scenes comprehensively. To characterise the world around us comprehensively vis-à-vis its visual and non-visual physiologically-relevant properties, we started an image-capture campaign to map out the spectral, spatial and temporal properties of both indoor and outdoor natural scenes across a wide range of geographical and seasonal contexts.

2. Methods

We developed a multi-modal, minimal-parallax image capture setup for capturing natural scenes comprehensively. We are collecting radiance images using an α-opic imaging radiometer (40°x48° FOV, 2712x3388 px^2), spectral irradiance measurements using a high-resolution spectroradiometer (380-780 nm, 1 nm resolution), illuminance and colorimetric (xy) measurements (~8 Hz), depth information using a depth camera (15 fps), and uncalibrated wide-field RGB videos (60 fps). All measurement devices, controlled by a laptop are integrated in a compact box (42x32x27 cm^3), which can be mounted on a tripod. Power is supplied through external batteries, making the system suitable for both indoor and outdoor use. In addition to the primary light-based data, we comprehensively describe the scenes using a novel metadata schema containing location, weather and other information. We collect natural scene data using two distinct protocols. First, in a time-lapse protocol, we collect data from the same scene over the course of a day. Second, in a trajectory protocol, we are simulating a hypothetical trajectory of an individual throughout the day, thereby capturing plausible natural scenes that people might be exposed to throughout the day.

3. Results

We have finished piloting and technical checks and are now collecting time-lapse data across various natural scenes. We have subjected our image-capture setup to a rigorous cross-validation check, indicating high between-device agreement for related quantities. Our setup has been proven to be portable for use in field measurements, facilitating the development of a geographically unbiased, worldwide database, which we plan to develop over time and make available.

4. Conclusions

Our data collection campaign will yield highly significant real-world data for developing novel approaches in understanding illumination and scenes in the real world. All data captured with our system are converted to physiologically relevant, cone-, rod- and melanopsin-based quantities and metrics to relate our data to lighting recommendations and guidelines, thereby creating the first open-access reference resource for the spectral, spatial and temporal properties of natural scenes.

OP82

EFFECTS OF FULL-DAY DYNAMIC LIGHTING PATTERNS ON HORMONE CONCENTRATION, CORE BODY TEMPERATURE AND SUBJECTIVE ALERTNESS AT BEDTIME IN CONFINED SPACES

Wang, T.Y.[1,2], Shao, R.D.[1,2], Hao, L.X.[1,2]
[1] College of Architecture and Urban Planning, Tongji University, Shanghai, CHINA, [2] Key Laboratory of Ecology and Energy-saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai, CHINA
haoluoxi@tongji.edu.cn

1. Motivation, specific objective

Due to the lack of daylight in confined spaces, it is difficult for people to sense the changes in time, which can easily lead to problems such as disrupted rhythms and sleep disorders. In order to improve the physical and mental health of people staying in confined spaces for a long time and reduce the "social jet lag" between their circadian rhythm and shift schedule, it is urgent to introduce dynamic lighting patterns that meet the needs of human circadian rhythm and actively intervene in the sleep and circadian rhythm of people.

2. Methods

A total of 20 male subjects (aged 22.60 ±1.88 years old) were recruited for the lighting experiments in the underground confined lab for 4 weeks. A within-group design was used in the experiment, with one lighting pattern each week. The current situation is simulated in the 1st week, with a static lighting pattern (6000K, 300lx) and a fixed work schedule. In the 2nd and 4th weeks, a dynamic lighting pattern (high lighting stimulus in the morning and dark light in the evening) was used to induce the circadian phase shift forward. The work and rest schedule in the 2nd week was forcibly moved forward by 2 hours, but the schedule remained fixed in the 4th week. In the 3rd week, another dynamic lighting pattern (strong lighting stimulus in the evening) was used to induce the circadian phase shift backwards, and the work and rest time remained fixed. By the experimental method of repeated measurement, the salivary melatonin and cortisol concentration, core body temperature (CBT, tympanic temperature), and subjective alertness (Karolinska scale score, KSS) at bedtime were collected every day. The changes in the circadian rhythm of the participants were comprehensively evaluated based on these subjective and objective data.

3. Results

The results showed that the concentration of melatonin and KSS scores at bedtime in the 1st week showed a daily downward trend, which was the opposite in the 2nd and 4th weeks. Melatonin concentration and KSS scores at bedtime were consistently the lowest in the 3rd week and significantly lower than that in other weeks ($p<0.05$). The concentration of cortisol at bedtime was the highest in the 3rd week, which was significantly higher than that in the 1st week ($p=0.003$), meaning the high lighting stimulation generally increased the level of alertness and excitement at night. Under the dark light before sleep in the 2nd and 4th weeks, cortisol concentrations were lower than those in the 3rd week, in which the 29th night was significantly lower than the 22nd night ($p=0.026$). Under the high lighting stimulus at the night of the 3rd week, the CBT at bedtime was significantly higher than that in the 2nd and 4th weeks ($p<0.05$), and the dark light in the evenings of the 2nd and 4th weeks led to a daily decrease of CBT and sleepiness at bedtime.

4. Conclusions

The effects of lighting on the concentration of melatonin and cortisol, CBT and subjective alertness showed cumulative effects. As the number of intervention days increased, the effects of the intervention became more pronounced and also indicated the effects of lighting history. Under the static lighting pattern, the melatonin concentration and subjective alertness at bedtime showed a trend of decreasing day by day. The changing trend of cortisol concentration and CBT was exactly the opposite, consistent with the backward trend of the circadian rhythm. Dynamic lighting patterns will effectively induce the shift of circadian rhythm, and can be customized according to the adjustment of personal "social jet lag". In addition, the combination of lighting parameters such as the spectrum and illuminance at different times can be further optimized to achieve a more efficient design of circadian lighting.

OP83

EFFECTS OF ZERO BLUE LIGHTING ON SLEEP, MOOD AND SUBJECTIVE ALERTNESS OF OCCUPANTS IN ANTARCTIC

Wang, Y.[1,2], Dai., S.[1,2], Shao, R.[1,2], Hao, L.[1,2]
[1] College of Architecture and Urban Planning, Tongji University, Shanghai, CHINA, [2] Key Laboratory of Ecology and Energy-saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai, CHINA
haoluoxi@tongji.edu.cn

Abstract

1. Motivation, specific objective

The continuous darkness during the Antarctic polar night defies the light-dark cycle required for normal human life, and the extreme light environment has negative effects on occupants such as sleep disturbances and emotional disorders for the Antarctic Research Expedition on the station. It is of great significance to explore the lighting patterns to improve the physical and mental health of polar expedition members and realize precise intervention for improving the quality of Antarctic indoor environment and the life quality of expedition members.

2. Methods

The experiment was carried out from 4 June to 8 July 2021 at the Chinese Great Wall Station in Antarctica, and 10 male expedition members (aged 36.70 ± 8.46) on the 37th Antarctic Science Research Overwintering Mission were recruited. A 34-day experiment with a specific 2-hour lighting pattern before sleep time was conducted. The experimental period included 1 week of sleep and rest adjustment before the test, 2 weeks of lighting test and 1 week of lighting flushing phase, and 1 week of observation after the test.

An intra-group crossover design was adopted. Each subject was exposed to zero blue lighting pattern (1800K, 300lx vertical illuminance at eyes) for 1 week and warm white lighting pattern (3000K, 300lx vertical illuminance at eyes) for 1 week.

During the experiment, participants wore sleep bracelets and filled in sleep diary every day, and completed the Pittsburgh Sleep Quality Index (PSQI) and the Beck Depression Inventory (BDI) on the last day of each week. Subjective alertness was evaluated every half hour during the lighting experiment by Karolinska Sleepiness Scale (KSS). The objective and subjective data were analysed comprehensively to evaluate the changes in sleep and emotional of the expedition members under different lighting patterns during the polar night.

3. Results

The results showed that the total sleep duration under zero blue lighting pattern (ZLP) in a week was higher than that of warm white lighting pattern (WLP). The number of awakenings in the WLP per week was lower than those in the ZLP, and the sleep continuity was better. PSQI and BDI scores in the WLP were lower than those in the ZLP, and the sleep quality and mood state were better. The KSS scores in both lighting patterns showed an hourly increasing trend, and the sleepiness level increased. The KSS scores in the ZLP increased more than that in the WLP. The ZLP had positive influence on sleep aid before bedtime. There were no significant differences in the time of falling asleep, waking up and sleep efficiency under different lighting patterns.

4. Conclusions

The active intervention lighting during the polar night had a significant effect on the sleep and mood of the Antarctic Research Expedition. The zero blue lighting effectively increased the total sleep time of expedition members and also contributed to sleep fast. The emotional state of the members was higher at warm white lighting in comparison. Light had a historical effect, and the data showed that the number of awakenings was the least in the observation week

after the experiment, and the time of falling asleep and waking up were earlier than those in the previous 4 weeks. As a result, the lighting may have after-effects on the sujects that are not fully manifested in the moment of lighting exposure. Due to the special conditions in Antarctic and the small sample size, the lighting dose will be further investigated on the effective improvement of the physical and mental health of expedition subjects during polar night.

OP84

EVALUATION ANNUAL DYNAMIC LIGHT VARIATION FOR NON-VISUAL EFFECTS: A CASE STUDY IN GROUND FLOOR CLASSROOMS OF CHINESE MIDDLE SCHOOL BASED ON LARK 2.0 SIMULATION TOOL

Xu, J.[1], Hao, H.[1], Tong, D.[1]
[1] School of Architecture, Soochow University, Suzhou, CHINA
xujunli@suda.edu.cn

Abstract

1. Motivation, specific objective

In recent years, the non-visual effects of classroom light environment have received increasing attention. In China, students spend most of their day in the classroom. Daylight provides high-level visual illuminance and is an ideal light source for non-visual effects. However, ground floor classrooms cannot provide sufficient illuminance by daylight alone due to heavy shading from the surrounding environments and buildings. In actual usage, classroom space are often lit with electric light.

Non-visual lighting is a relatively new area of research. Some standards or recommendations have proposed evaluation metrics for non-visual effects of building spaces to ensure the physical and mental health of users. Brown et al. suggested a minimum melanopic equivalent daylight illuminance (melanopic EDI) of 250 lx at the eye level throughout the daytime and Chinese standard recommendation for horizontal illuminance of 300 lx at the work plane. However, the annual light information for various areas of classroom in actual use is not known.

Therefore, in this study, a typical classroom in a middle school in Suzhou was selected. The melanopic EDI and horizontal illuminance in different areas of the classroom under daylight conditions were obtained using the Lark Spectral Lighting v2.0 (Lark 2.0) simulation tool, and were examined to determine whether they met the recommendation of Brown et al. and Chinese standard. Then, the percentages of effective stimulus days for melanopic EDI, the average daily effective stimulus hours, and the impact of the seasonal difference were evaluated. In addition, a comparative analysis of light variation in each area after supplementing with the electric light was performed. The study provides recommendations for optimizing healthy light environments in non-visually driven classrooms.

2. Methods

A classroom model was created in Rhinoceros 6, mimicking the classroom space on the ground floor of a middle school in Suzhou, China. The room dimensions were set to 9.0 x 8.7 x 4.2 m. The main lighting window was on the north side of the room, the corridor was on the south side, and the surrounding classrooms were built on both sides of the target classroom. In addition, teaching facilities such as desks, chairs and blackboards were placed inside.

A dynamic light environment simulation platform was built using the Lark 2.0 plugin for Grasshopper. The meteorological data, sky spectral power distribution values (D65), glass spectral transmittance and material spectral reflectance files were input into the platform respectively. The comparison was carried out between the simulation results and the measured values to verify its accuracy by modifying the geometric parameters and glass spectral transmittance of the model.

A 3X3 (2.5m spacing) sensor grid was arranged in the learning area of the classroom, and the horizontal illuminance (0.75 m) at the work plane and the melanopic EDI (1.2 m) at the eye level were obtained for these grids. Daylight simulation were performed at 1h intervals over the whole year. In addition, annual light variations were examined under daylight and electric lighting conditions.

3. Results

The study aims to investigate the annual light variations in specific areas of the classroom space using Lark 2.0 simulation tools, focusing exclusively on whether the daylight intake meets the recommendation of Brown et al. for melanopic EDI and Chinese standard for horizontal illuminance. The duration of meeting the recommended requirements per day was defined as daily effective stimulus hours. When the daily effective stimulus hours of melanopic EDI greater than or equal to 4 hours, it was defined as an effective stimulus day.

The results showed, under daylight conditions, the percentages of effective stimulus days of a year for melanopic EDI near the north window of the classroom accounted for more than 80%, the percentages in the middle area were about 50%, and the front area was difficult to meet the recommendation. In the central and south window areas of the classroom, the average daily effective stimulus hours of melanopic EDI were significantly higher than the average hours of horizontal illuminance. The average daily effective stimulus hours of melanopic EDI in the rear area was relatively low (1.19 ± 1.41 h), and the average effective stimulus hours of horizontal illuminance was almost zero, since this area was blocked by the wall. Moreover, there was no effective stimulus hour for both melanopic EDI and horizontal illuminance at the front area.

The horizontal illuminance and melanopic EDI values in the south window area of the classroom showed a tendency to be low in summer and high in winter due to the influence of solar altitude angle change and corridor. The melanopic EDI values of the front area were not much different in summer and winter, probably because of the lack of daylight in the field of view, additional electric lighting will be needed to meet the recommendation.

Additionally, under daylight and electric lighting conditions, the percentages of effective stimulus days for melanopic EDI in the north window area of the classroom were nearly saturated, while the front area still could not meet the requirements, and the percentages in the rest of the area were significantly increased.

4. Conclusions

In summary, this study illustrated the complexity of dynamic daylight distribution in classroom, but also provided guidance on how to supplement the required electric lighting in response to daylight variations. The findings can be seen as an opportunity to rethink how we optimize light in accordance with actual light information in classroom, by focusing on light that reaches the eye and the light on the horizontal desk to meet both visual and physiological needs of students.

Session PA7-2
D1 - Colour

Wednesday, September 20, 12:30–14:05

OP64

CHARACTERIZING CIECAM02 PREDICTIONS OF PERCEIVED COLOURFULNESS AND HUE CHANGES AT DIFFERENT LIGHT LEVELS DUE TO HUNT EFFECT

Li, J., Ohno, Y.
National Institute of Standards and Technology, Gaithersburg, USA
jiaye.li@nist.gov

Abstract

1. Motivation, specific objective

Colour appearance models are important in colour-related applications, such as characterization of light source colour rendition, colour difference evaluation. The CIECAM02 colour appearance model takes into account many colour appearance phenomena, including the Hunt Effect, a visual phenomenon in which the perceived colourfulness of objects changes with the adapted light level. CAM02-UCS is a colour space based on the CIECAM02 model, which is used to present the experimental results in current study. According to our past experimental results, it seemed that the prediction on Hunt Effect by CIECAM02 was not sufficiently accurate at lower illuminance levels (below 1000 lx) though it was fairly accurate at higher illumination levels (above 1000 lx).

The purpose of this study is to characterize the predictive performance of CIECAM02 by comparing with experimental results on Hunt Effect over a wide range of illuminance levels. For this purpose, additional experiments on Hunt Effect at lower illumination levels (30 lx, 100 lx, and 300 lx) were conducted. The obtained results, together with the previous experiments at higher illumination levels (100 lx, 1000 lx, and 6000 lx), were compared with the predictions by CIECAM02.

2. Methods

The object colour matching experiment was conducted for illuminance pairs of 30 lx/ 100 lx and 100 lx/300 lx with a haploscopic viewing condition, similar to our previous Hunt Effect experiments (published in 2020 and 2022). A double-booth equipped with 16-channel spectrally tunable LED light sources were used to provide two adapting fields at different illuminance levels side by side with the same CCT (≈6500K) and D_{uv} (≈0.0007) so that each eye of the observer was adapted to each illuminance level. The broadband spectral power distribution of the two adapting fields (for left eye and right eye) were carefully adjusted to be nearly the same ($\Delta u'v'$ chromaticity difference <0.0003) to avoid the effect of chromatic adaptation. The colour samples are 5.5 cm x 5.5 cm square patches of highly saturated colour, which is approximately 6 degree viewing field size from the observer's perspective. Each reference sample was presented under the lower illuminance field placed near the center partition wall of the two booths, while the colour matching samples with varied chroma and hue were presented under the higher illuminance field. Five reference colours (red, green, blue, yellow and grey) were used in the experiment. The grey samples were specifically for lightness matching, to measure the degree of imperfect adaptation in the haploscopic viewing condition and to correct the experiment results. The 20 matching samples of each colour were carefully prepared to have their CAM02-UCS *a', b'* coordinates (under D65) uniformly distributed on a grid with specific intervals of chroma and hue, determined by the results from our previous experiments. For each colour, the matching samples were arranged in 5 rows × 4 columns, mounted on a grey colour board. The spectral radiance of the adapting fields were measured with a tele-spectroradiometer before each experiment session.

Before the experiment, observers with normal colour vision (tested by the 24-plate Ishihara test) were first adapted to the haploscopic viewing fields for around 5 minutes. During the experiment, the observers were asked to quickly choose a matching colour sample having the closest colour appearance to the reference sample. Observers were adapted to the adapting field for 1 min before next colour of samples was presented. The five reference colours and the two adapting condition pairs were presented randomly in each experiment session to

avoid order bias. The adapting conditions were repeated for each observer by switching the booths left and right. Thus, a total of 20 matches were performed for each observer for each experiment session: 5 reference colours x 2 adapting condition pairs x 2 (repeats). The experiment took about one hour for each observer. The experiments are still in progress and tentative results are reported in this abstract. The full results with 15 subjects will be reported in the proceedings paper.

3. Results

The colour coordinates of the reference sample and the observer-matched samples in the current and previous experiments were calculated and plotted in CAM02-UCS space, along with their standard deviation ellipses, to assess matching accuracy and inter-observer variation. The difference in chroma and hue values for a total of three different adapting condition pairs (including the 100lx/1000lx condition in previous experiment) were compared. The results showed that compared to 300 lx, the perceived chroma $C^*_{a'b'}$ at 100 lx decreased on average 4.8%, 3.2%, 4.8%, 6.3% for red, green, blue, and yellow, and there were also hue shifts up to 2.2°. Higher chroma decreases (6.9%, 5.4%, 7.5%, 6.9%) have been found for the 30lx/100lx condition. These results lie reasonably well along the prediction lines by the results of previous experiment (100 lx/1000 lx condition). Then the CIECAM02 model incorporating the Hunt Effect model was used to predict our results. Substantial differences between the calculated CIECAM02 a_M, b_M coordinates of the reference samples (predicted for lower illuminance levels) and those of the matching samples (under higher illuminance levels) were found. For example, the calculated decrease of colourfulness for 30 lx/100 lx condition by CIECAM02 was found to be 8.8%, 7.0%, 9.5 %, 6.0 %, for red, green, blue, and yellow, which are notably larger than those of our experimental results (in CAM02-UCS), except yellow. The significance of the difference in matched colourfulness and hue values for different adapting condition pairs and (reference) colours were determined with a repeated measures MANOVA test.

4. Conclusions

Experiments on Hunt Effect at the lower illuminance levels were conducted, which added to a wider illuminance range of experimental data on Hunt Effect. The comparison results showed that the prediction of Hunt Effect by CIECAM02 (with varied adaptation luminance as input) is not sufficiently accurate at lower illumination levels. While further experimental data will be useful to verify this finding, such an improvement may be considered in next version of color appearance model. This result has important implications not only for the prediction of color appearance, but also for color-related applications, such as the derivation of better color fidelity models based on the Hunt Effect.

OP32

A COLOUR FIDELITY MODEL BASED ON HUNT EFFECT

Ohno, Y. and Li, J
National Institute of Standards and Technology, Gaithersburg, USA
ohno@nist.gov

Abstract

1. Motivation, specific objective

The 2017 CIE Colour Fidelity Index R_f (CIE 224) was published for accurate scientific use, and not recommended for rating of products, even though this index uses the latest formulae and a large number of test samples. This recommendation is based on consideration that not only fidelity but also other perception effects such as preference need to be considered for evaluation and design of lighting products. One of the important conditions not considered in R_f is the light level of the lit environment. It is becoming well-known that perceived chroma of objects is less at lower light levels, which is known as Hunt Effect. The perceived hue also shifts at low light levels. Several recent studies demonstrated that Hunt Effect is effective and significant at the normal indoor lighting levels, indicating that objects under typical indoor lighting environment are appearing less saturated compared to that under outdoor daylight, the light level of which is more than two orders of magnitude higher than typical indoor lighting. Based on this, if outdoor daylight is considered as the reference condition, object colours will appear more accurate when object chroma is slightly enhanced (by lighting) at typical indoor lighting environment. Incidentally, many experimental studies in the past showed that colour rendition with slightly enhanced chroma is preferred in many applications, and this effect has been considered as observers' preference. However, this preference for increased chroma may be explained as due to higher colour fidelity if the Hunt Effect is considered. Thus, the objective of this study is to develop a computational model that can predict such a dynamic colour fidelity based on Hunt Effect and to investigate its usefulness for practical evaluation of light source colour rendition.

2. Design of a Dynamic Colour Fidelity model

An attempt was made to develop a colour fidelity model implementing the Hunt Effect by using the experimental data recently obtained by the authors, on the changes of perceived chroma and hue at 6000 lx, 1000 lx, and 100 lx (published), and also 300 lx, 100 lx, and 30 lx (to be published). This colour fidelity model is designed to predict colour fidelity for a given input illuminance level, in a range of possible indoor lighting level (30 lx to 3000 lx), and is named *Dynamic Colour Fidelity* (*D-CFI*) model in this paper. Prior to designing this model, our experimental data were compared with CIECAM02 predictions but they did not agree sufficiently well (another abstract submitted), thus it was not used.

The D-CFI model was developed by modifying the formula for CIE R_f, using the same object colour space and same set of test colour samples. The colour differences in CAM02UCS of the 99 test colour samples are calculated for a given test light source and the reference illuminant, the same way as in CIE R_f, but the reference illuminant is modified for D-CFI. The modified reference illuminant does not exist as spectral data but it is dynamic in a way that the colour coordinates (chroma and hue) of the test colour samples under the reference illuminant are modified based on Hunt Effect. The authors' experimental data on Hunt Effect are used, which are available for only four hues (red, yellow, green, blue) and five illuminance levels (6000 lx, 1000 lx, 300 lx, 100 lx and 30 lx). These available experimental data of chroma decrease (%) and hue shifts (°) were fit and interpolated as a function of illuminance and hue angle, and applied to the calculation of all 99 test samples. Therefore, the gamut area of the D-CFI reference illuminant, plotted by the average color coordinates of the 16 hue bins covering the whole hue angle, is slightly larger than that of CIE R_f for a typical indoor lighting illuminance level (e.g., about 6% larger at 300 lx).

The resulting D-CFI general colour fidelity index (corresponding to R_f in CIE 224) is called *dynamic general colour fidelity index*, in this paper, with symbol $R_f(E)$, which is a function of input illuminance E (lx). For 3000 lx and higher, $R_f(E) = R_f$. For illuminance levels lower than 30 lx, the value will be linearly extrapolated. The $R_f(E)$ value will be maximum (100) for light spectra that would increase object chroma to bring the same colour appearance as outdoor daylight by Hunt Effect prediction. Thus, a Planckian radiation no longer makes maximum value for $R_f(E)$. This model is expected to provide more accurate colour fidelity evaluation in real lighting environment incorporating the effects of illuminance level on colour appearance perception.

3. Evaluation of the model with the results of previous experiments

The D-CFI model was developed on a spreadsheet software and evaluated by calculating $R_f(E)$ values for many light sources used in previous vision experiments (those published by the authors from 2015, 2017, and 2019) and compared with subjects' rating in these experiments. The 2015 experiment was made at 300 lx, the 2017 experiment at 250 lx, and 2019 experiments at 1000 lx and 100 lx, viewing fruits and vegetables and skin tones in a simulated interior room setting illuminated by spectrally tunable light sources, which can increase or decrease object chroma mainly in red-green directions. In these previous experiments, graphs were plotted with chroma shift (from -16 to 16 ΔC^*_{ab} set for a red sample) by test light on horizontal axis and the subject's rating of object appearance (the percentage of test light perceived better than the reference) on the vertical axis. $R_f(E)$ values were calculated for each of these light spectra and the illuminance used, and plotted on the same graphs of the previous study results, and compared with the visual evaluation results. The relative Rf(E) curves and subject rating curves agreed well with the peaks occurring at nearly the same ΔC^*_{ab} levels. Further, the $R_f(E)$ curves were compared with R_f and CRI R_a curves plotted in the same graphs, which obviously show that $R_f(E)$ has significantly higher correlation with subjects' visual rating of lights at different chroma saturation levels than R_f and R_a.

4. Conclusions

A colour fidelity model incorporating Hunt Effect was developed based on the experimental data on Hunt Effect. Though the experimental data are still limited, and the variation of light spectra used in this analysis was limited, the analysis demonstrated that the developed D-CFI model predicts observers' rating on colour rendition sufficiently well for lights with varied chroma saturation at typical indoor lighting level, and this model may be useful as a measure for colour rendition, though this model evaluates colour fidelity (considering light level). Further vision experiments on the Hunt Effect and analyses with various light sources are needed in the future to improve this model for practical use.

OP48

TESTING COLOUR-DIFFERENCE FORMULAS FROM LMS COLOUR SPACES INSPIRED FROM CIELAB

Wang, L.[1], **Li, C.J.**[1], Melgosa, M.[2], Xiao, K.D.[3], and Gao, C.[1]
[1] School of Computer and Software Engineering, University of Science and Technology Liaoning, Anshan, CHINA, [2] Department of Optics, University of Granada, Granada, SPAIN
[3] School of Design, University of Leeds, Leeds, UK
794962485@qq.com

Extended Abstract

Colour-difference formulas and uniform colour spaces are important within CIE (International Commission on illumination) colorimetry. Currently, the CIE 1976 $L^*a^*b^*$ colour space, or simply CIELAB, is one of the CIE-recommended approximately uniform colour spaces, and the colour-difference formula associated to CIELAB is simply the Euclidian distance between the coordinates of the two samples in the $L^*a^*b^*$ colour space. Both the CIELAB colour-difference formulas and the colour space have been widely applied in various industries such as plastic, printing & packing, paint, textile & garment, automobile, cross media colour image reproduction, color management, etc.

In 2020, CIE set up the Technical Committee 1-98 “A Roadmap Toward Basing CIE Colorimetry on Cone Fundamentals” to initiate investigation on establishing a new colorimetry based on the cone response signals LMS. It is expected that in the near future, this new colorimetry (denoted as LMS colorimetry in this paper) will replace the current CIE colorimetry (denoted as XYZ colorimetry). With the new LMS colorimetry, what colour-difference formula should be used? It is clear that it can be proposed a colour-difference formula directly based on the LMS space. Such colour-difference formula can be defined in the $X_FY_FZ_F$ space (LMS-based tristimulus values, calculated from cone-fundamental-based tristimulus functions, according to CIE 170-2:2015) since CIE has already defined a transformation between LMS and $X_FY_FZ_F$ (CIE 015:2018). It is natural to ask:

1) What will be the performance of the Euclidian distance in LMS, used as colour-difference formula?
2) What will be the performance of a LMS colour-difference formula inspired in CIELAB, and denoted here as CIELAB(LMS), where XYZ were replaced by LMS in CIELAB equations?
3) What will be the performance of a $X_FY_FZ_F$ colour-difference formula inspired in CIELAB, and denoted here as CIELAB($X_FY_FZ_F$), where XYZ were replaced by $X_FY_FZ_F$ in CIELAB equations?
4) Can these CIELAB formulae (CIELAB(LMS) and CIELAB($X_FY_FZ_F$)) be improved for better predictions of visual colour differences?

To answer above questions, visual colour difference datasets based on LMS space are needed. Current available visual colour difference datasets (CIE 217:2016) include the COM-corrected and four individual datasets (BFD-P, Leeds, RIT-DuPont and Witt), all of them defined in terms of XYZ values of pairs of samples, under specified illuminants and CIE 1964 standard colorimetric observer, together with their corresponding visual differences. Therefore, we have generated spectral reflectance factors between 380 nm and 780 nm at 1 nm intervals based on given XYZ values for each pair of samples in the four individual datasets previously mentioned. Thus, these four individual datasets and the COM-corrected dataset are defined in terms of spectral reflectance factors and visual colour differences, which made possible to answer the questions posed above.

The results found from computation of *STRESS* values (CIE 217:2016) lead to the next main conclusions: i) Similar to XYZ space, LMS is not uniform and the Euclidian distance in LMS cannot be proposed as a good colour-difference formula; ii) CIELAB(LMS) performs worse than CIELAB. iii) CIELAB($X_FY_FZ_F$) is better than CIELAB(LMS), but it is still worse than CIELAB; iv) Both CIELAB($X_FY_FZ_F$) and CIELAB(LMS) can be improved by keeping the structure of CIELAB and optimizing the values of the parameters. In this way, we found an improved CIELAB($X_FY_FZ_F$) which is slightly better than CIELAB. Hence this improved CIELAB($X_FY_FZ_F$) can be used as an approximately uniform colour space with its associated colour-difference formula in LMS colorimetry. It is expected that findings in this paper provide valuable information to CIE TC 1-98 and this improved CIELAB($X_FY_FZ_F$) be considered a candidate for uniform colour spaces and colour-difference formulas in LMS colorimetry, since it is as simple as current CIELAB and its performance is slightly better than the one of CIELAB for the visual colour difference datasets considered here.

OP54

METRICS INDICATING PROPERTIES OF LIGHT COLOUR AND SUBJECTIVE EVALUATION OF COLOUR APPEARANCE

Iwata, T.[1]
[1] Shibaura Institute of Technology, Tokyo, JAPAN
iwata@shibaura-it.ac.jp

Abstract

1. Motivation, specific objective

Main metrics which indicate colour property of light are correlated colour temperature (CCT) and general colour rendering index (Ra). As a complementary value to CCT, duv is used to describe the distance of a light colour point from the black body curve. Since limitations of Ra have been recently addressed, especially for solid-state light sources, the general colour fidelity index Rf has been developed. However, both Ra and Rf indicate one aspect of colour quality not considering perception-related colour quality. On the other hand, the colour gamut area ratio (Ga), which is the ratio of the gamut area of the sample light source to the gamut area of the reference light source and is often less than 100 has been proposed as an evaluation method corresponding to subjective colour appearance such as vividness and desirability of colour rendering. Ga is based on the eight test colour samples (TCS) used to calculate Ra. Perception-related quality as well as fidelity of colour appearance is required for lighting.

The purpose of this study is to identify the relationship between these metrics indicating properties of light colour and subjective evaluation of colour appearance.

2. Methods

Prior to the subjective experiments, the spectral distribution of light sources around us was measured and CCT, duv, Ra, Rf, and Ga were calculated to understand the relationship between them.

For the subjective experiment, the lamps with variable light colour were adjusted to obtain the following pair of light sources (P and Q). CCT of P and Q are equal, Ra of P is smaller than that of Q, and Ga of P is larger than that of Q. With CCT of 2500 K, the light source P has Ra of 87and Ga of 112 while the light source Q has Ra of 92 and Ga of 99. With CCT of 4000 K, P has Ra of 83 and Ga of 93 while Q has Ra of 86 and Ga of 88. With CCT of 14000 K, P has Ra of 84 and Ga of 116 while Q has Ra of 89 and Ga of 102. With a CCT of 8000 K, such a combination of light sources could not be obtained. The range of duv was from -0.02 to 0.02.

The object to be evaluated was wood pieces painted in six different colours (white, black, dark brown, brown, beige, and bronze) and a flower painting. Each was illuminated by the light source P and the light source Q, respectively and illuminance on the object was set at 380 lx. The "naturalness," "vividness," and "desirability" of the colour appearance were evaluated by using paired comparison method. Ten students (5 males and 5 females) with normal colour vision participated in the experiment as subjects.

3. Results

The results of calculation of the metrics showed that Ra and Rf showed a high correlation, and the difference in value was about 0 to 3, when Ra is more than 80. A positive correlation was found between Ra and Ga, however, there were cases where Ra was less than 90 with more than 100 of Ga. Although positive and negative correlations between duv and Ra were predicted when duv was negative and positive, respectively, no correlation between duv and Ra was observed for both negative and positive duv. It was found that there was a negative correlation between duv and Ga.

The results of the subjective experiment showed that there were no significant differences in naturalness, vividness, or desirability ratings between the viewing objects (wood pieces and paintings) for all CCT conditions. With CCT of 2500 K, as with CCT of 4000 K, the light source P was rated higher than the light source Q for naturalness, vividness and desirability. With CCT of 14000 K, the light source P was rated lower for naturalness than the light source Q, while the light source P was rated higher for vividness and desirability than the light source Q.

4. Conclusions

It was shown that higher Ra did not necessarily result in higher Ga. The results of the subject experiments showed that naturalness evaluation did not necessarily high even if Ra was high. It was also shown that regardless of the value of Ra, the value of Ga affected the vividness and desirability evaluation.

OP65

A NEW DATABASE OF HUMAN SKIN COLOUR

Lu, Y.[1], Xiao, K.[1,3], Pointer, M.R.[1], Sueeprasan, S.[2], Li, C.[3]
[1] University of Leeds, Leeds, UK, [2] Chulalongkorn University, Chulalongkorn, THAILAND, [3] University of Science and Technology Liaoning, Liaoning, CHINA
sdyl@leeds.ac.uk

Abstract

1. Motivation, specific objective

Skin colour is one of the most familiar colours that we humans are exposed to. Reliable and accurate skin colour measurements are of vital importance in a wide range of applications such as medical diagnosis and prostheses manufacture, skin colour reproduction in photography, and skin assessment in cosmetic and personal healthcare industries, etc. However, due to the structure of human skin, the measurement results may largely depend on the techniques of measurement and the measurement protocol. Meanwhile, there are large variations between individuals of different ethnic groups, genders, age groups, and across different body locations. This work is carried out under the scope of CIE TC 1-92 Human Skin Colour Database. The objectives of this work are to establish a comprehensive human skin colour database and to investigate the variations mentioned above.

2. Methods

In this work, nine separate data sets of spectrophotometric measurements of skin reflectance were collected from different laboratories around the world with more than 10 000 skin patches have been measured. Most skin reflectance data covered the visible spectral range from 380 nm to 780 nm, while some of the data was limited to the restricted range of 400 nm to 700 nm. The skin colour characteristics of 6 ethnic groups (Caucasian, Chinese, Kurdish, Thai, Pakistani and African), 11 body locations (forehead, cheekbone, cheek, nose tip, ear lobe, chin, neck, outer arm, inner arm, back of the hand, palm, and ring finger), both genders, and various age groups were covered. The skin spectra data were all measured using spectrophotometers and then converted to CIE colorimetric data (2° standard observer, standard illuminant D65) including the tristimulus values, x, y chromaticity coordinates, and CIELAB parameters.

3. Results

Based on the skin colour and spectra data of all the measurements, a new human skin colour database was established. Skin colour differences and variation were evaluated as a function of ethnicity, body location, gender, and age group in the CIELAB colour space. Different ethnic groups exhibited significantly different skin lightness and yellowness, which mainly results from different quantities of melanin in the dermal layers. Caucasian skin exhibits the highest lightness (L*) value and African skin the lowest value; Thai skin exhibits the highest yellowness (b*) value and African skin the lowest value. Facial redness (a*) is similar across the four ethnic groups. The skin colour gamut of African people was found the smallest compared to other ethnic groups. Different body locations showed significant variations in redness and yellowness. The ring finger showed the highest redness (a*) value and the inner arm the lowest. The nose tip showed the highest yellowness (b*) value and the palm the lowest. The redness of skin was found mostly affected by the body location, rather than ethnicity. Females were found to generally have a lighter skin colour or a consistently higher spectral reflectance than males across different ethnic groups. Different age groups didn't show significant differences in skin colour, and the variations are much smaller compared with those found in the other comparisons above.

4. Conclusions

The new human skin colour database provides over 10 000 sets of spectral measurements of human skin colour along with the CIE colorimetric data. The LSDB covers subjects of different

ethnicity, gender, age, and body location, which are important and depend on the requirements of the particular study that needs the measurement of human skin colour. Such skin colour variations have been quantified in the current work. Variations between different ethnic groups were mostly found in lightness and yellowness; variations between body locations were primarily found in redness and yellowness. whereas variations in gender were mainly related to lightness. The new database is expected to benefit numerous fields and applications related to human skin.

Session PA8-1
D1/D3 - Glare and discomfort

Wednesday, September 20, 14:30–16:05

OP56

IS THERE AN EFFECT OF MACULAR PIGMENT DENSITY ON DISCOMFORT GLARE IN INDOOR DAYLIGHT CONDITIONS?

Jain, S.[1], Karmann, C.[2], Wienold, J.[1], Andersen, M.[1]
[1]Laboratory of Integrated Performance in Design (LIPID), École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, SWITZERLAND, [2]Laboratory of Architecture and Intelligent Living (AIL), Karlsruhe Institute of Technology (KIT), Karlsruhe, GERMANY
sneha.jain@epfl.ch

Abstract

1. Motivation and objectives

Discomfort glare caused by daylight should be minimized as it can lower the productivity and negatively impact daylight utilization in buildings. Reliable and accurate prediction models to evaluate and address it are therefore necessary. Existing glare models are all empirical models designed to best match the characteristics of the luminous environment with the reported subjective glare perception under which they were developed. While these prediction models allow a reasonable estimate of the average discomfort for a group of observers, they fail to account for the large variabilities that exist in individual glare perception since the physiological origin behind discomfort glare remains unexplained. Among the physiological factors studied previously for their influence on discomfort glare, macular pigment density in the retina emerges from the literature as one of the most promising factors that can potentially explain, to an extent, the large inter-individual variability observed in discomfort glare sensitivity.

Macular pigments in the retina exhibit a filtering mechanism that attenuate the chromatic aberration and reduces the scattered light reaching the photoreceptors, thereby improving visual function. The density of macular pigments varies widely across the human population, causing a large variation in the amount of short-wavelength light processed by the retina. Studies have found that people with higher macular pigment optical density (MPOD) show a higher tolerance to glare from electric light sources. However, this effect has only been studied in ophthalmological laboratory settings where the glare source was located close to fovea. The influence of macular pigment on discomfort glare from daylight in regular indoor spaces, where the glare source is typically off-fovea, thus still remains unknown.

To address this gap, our study aims to determine whether macular pigment density in the retina can have any influence on individual glare sensitivity in indoor daylit environments. We evaluate the discomfort glare sensitivity from the sun visible behind either color-neutral glazing or saturated blue-colored glazing, all with very low visual transmittance values. The blue tint was chosen since the absorption spectrum of macular pigments is dominant in the short wavelength region, making it a good candidate to reveal if there is an impact on glare sensitivity.

2. Methods

To determine the influence of macular pigments (MP) on glare sensitivity, we followed a psychophysiological approach in which measured macular pigment density was compared to participants' glare sensitivity in normal daylight office settings. Three independent user studies, involving a total of 152 participants, were brought together to investigate the effect of MP on glare sensitivity.

In all three studies, a similar methodology was followed: participants were exposed to pre-defined experimental conditions with direct sun as the glare source in their near peripheral field of view, while seating in an office-like test room. The room was equipped with either color-neutral or blue-colored glazed window towards the sun, manipulated in terms of visible transmittance to create the desired glare conditions. All the participants were young and healthy adults between the ages 18yrs to 30yrs without any ocular pathologies and with normal color vision.

Participants' sensitivity to discomfort glare was evaluated through survey questionnaires, where they rated the discomfort glare level experienced in each condition after being exposed to it for a duration of 5 to 10 minutes. The macular pigment density was measured using a macular pigment screener device that estimated blue light absorption by macular pigments using heterochromatic flicker photometry method. The focus of the analysis was to establish the relation between the participants' reported glare responses and measured MPOD, in order to determine the influence of macular pigment on glare perception.

3. Results

The measured MPOD between the participants were found to have large variations as reported by the literature with young and healthy adults. Comparing participants who did experience glare to the ones who did not report any glare in color-neutral glare scenarios, we found no significant difference in their measured MPOD values. This indicates that MPOD does not seem to have an influence on discomfort glare perception from the sun disc filtered by color-neutral glazing in the near-peripheral field of view.

With a blue-tinted glazing however, we did find a statistically significant correlation ($p<0.01$, $r=0.40$) between MPOD and the participants' glare perception: participants with higher MPOD tended to report glare less frequently than participants with lower MPOD values. This suggest that macular pigments help in attenuating discomfort from blue-colored glare source even when the source is at higher eccentricities where macular pigments are not concentrated. This leads to the hypothesis that the participants' free gaze behaviour in our study, unlike past studies, might have caused instances where sun was in fact close to the fovea.

4. Conclusions

Overall, the results demonstrate that MPOD cannot account for the inter-individual variability observed in discomfort glare perception for typical work scenarios (i.e., with free gaze behaviour and glare source outside the fovea) under neutral daylight condition, but can, in part, explain the variability when glare is perceived under saturated blue glazing. The outcomes have also led to a better understanding of the role of macular pigments in discomfort glare perception in indoor daylit environments.

OP18

INVESTIGATING THE ADDITIVITY OF GLARE SOURCES IN DISCOMFORT GLARE METRICS

Quek, G.[1,2], Wienold, J.[1], Andersen, M.[1]
[1]École Polytechnique Fédérale de Lausanne, Lausanne, SWITZERLAND, [2] Singapore University of Technology and Design, Singapore, SINGAPORE
geraldine_quek@sutd.edu.sg

Abstract

1. Motivation, specific objective

Given the complexities and variations of office spaces such as open-plan ones, the number of glare sources in real buildings may not be limited to one, as in most laboratory studies. The contrast effects of detected glare sources are typically summed together in glare metrics when predicting discomfort glare in a specific luminous condition. The summation is proportionate to the size of the glare source (ω_s) and is made mathematically sound because the variable's power is kept at 1. In the past, researchers have questioned whether the addition of glare sources in the calculation of glare metrics reflects user evaluations of discomfort glare in the luminous scene. Does the summation of the contrast terms in the formulae of glare metrics correlate to the degree of discomfort glare experienced by the observer when multiple detected glare sources are present in the scene?

2. Methods

We designed and carried out a user studies aimed at determining the extent to which existing models can predict occupants' perceived discomfort glare in dim daylit environments with the wider aim to extend glare experiments to this luminous range which are similar to those found in typical open-plan office spaces. To achieve the saturation and contrast effects in the targeted low-light range, four scenes varying the size and position of the glare source were designed using diffuser and low-transmission neutral-density films. Halfsquare_I had a glare source right above their line of sight, Halfsquare_P had the same glare source but at the periphery of the room, Halfsquare_2 had both these former glare sources present and Halfrect_C had a bigger glare source in the mid-periphery.

44 participants were recruited for the experiment and evaluated a total of 176 scenes. Each data point consists of photometric measurements (illuminance and luminance measurements using spot measurements and HDR imaging before and after the survey period) and are coupled with user responses on glare and other indoor environmental quality (IEQ) aspects that were solicited from a sampling questionnaire. After filtering out data points where the weather was not consistent during the evaluation period, 139 data points evaluated by 37 participants were used for subsequent data analysis. For the detection of glare sources, we used a fixed luminance threshold of 3000 cd/m^2, to ensure we cover the lower limit of the luminance of diffuse panels (around 4000 cd/m^2). Stray glare sources (less than 1000 pixels) from reflective surfaces with a were also re-integrated into the background luminance. After ensuring that the HDR images were processed and calibrated with a spot luminance measurement, glare metrics were calculated for each of the data points. Finally, we evaluate the descriptive statistics of the discomfort glare responses of each scene and compare the trends of median values of existing glare models to that of user responses.

3. Results

From the user studies, we observed that the addition of contrast effects does not necessarily generate more uncomfortable glare responses. Halfsquare_2 (with an additional glare source in the periphery compared to Halfsquare_I) is overpredicted by both DGI and DGI$_{mod}$ in

experiment 2, even though it should have a lower prediction value, based on the glare responses. Instead, both metrics predicted Halfsquare_2 is almost exceeding that of Halfsquare_I, which should have been the highest prediction value based on the glare responses.

We hypothesized that this phenomenon may be due to the method of additivity of the two glare sources in Halfsquare_2, which currently adds up both the contrast terms of the two sources. The summation of the contrast term for every detected glare source could result in over-prediction of Halfsquare_2 due to the addition of contrast effects of both central and peripheral glare sources. To investigate this, we recalculated glare metrics by keeping only the largest glare source (with the largest value of L_s*ω_s). However, this only resulted in a slight reduction in the median value of predicted glare models, and the user glare responses are still lower than the new median values.

This indicates that additivity only partially explains the effect, and other factors such as higher adaptation levels because of the secondary glare may also play a role in lowering the degree of discomfort glare in these cases. Other modifications to the main contrast term would be necessary to account for the lower glare responses in such situations.

4. Conclusions

The results of the user studies indicate that the presence of two glare sources may be perceived as less glary than when one glare source is present. This could be due to the second glare source, rather than being perceived as a second disturbing glare source, instead, it increased the adaptation level which could reduce the perception of discomfort glare from a glare source of the same luminance. Perhaps, the uniformity of lighting that resulted from the addition of the second glare source could also contribute to lower discomfort from glare. The summation of contrast terms of detected glare sources may sometimes slightly over-predict discomfort glare when using current summation methods. However, this may only explain the lower glare responses partially, and higher adaptation levels might be needed to be accounted in the main contrast term as well. More research is needed to address how and when glare sources should be summed in the glare metrics, to determine methods to differentiate the detection of the main glare source vs. other sources of light (which could also be electric lighting sources which are common in most office spaces) which could be balancing out the effects of the glare source through raising adaptation levels and uniformity of luminance distribution instead.

OP46

PERCEPTION OF GLARE IN RELATION TO THE CIE SCALE ON UNIFIED GLARE RATING AND THE IMPACT OF AMBIENT LIGHT ON BOTH UGR AND SUBJECTIVE GLARE INDEX SCALES (SGI)

Ekim, Z.[1], Govén, T.[2], Laike, T.[1]
[1] Lund University, Lund, SWEDEN, [2] Svensk Ljusfakta, Stockholm, SWEDEN
Zeynep.ekim@abm.lth.se

Abstract

1. Motivation, specific objective

Today the UGR tabular method according to CIE 117-195 and CIE 190-210, is practically the only one used for evaluation of glare in the lighting design process. It is important to investigate if the method is in line with the subjective perception of glare (SGI). The objective of the study was to investigate whether the perceived discomfort glare from commonly used lighting systems for workplaces is in agreement with the UGR calculation method currently used in lighting design to estimate the degree of discomfort glare. We have compared four different SGI with UGR in order to see how well they correlate. Another objective with the study was to investigate how important the room brightness is for the experience of discomfort glare. Therefore, the ambient light is taken into account in this study. Today the impact of ambient light is normally not considered in the calculation of discomfort glare when using the UGR tabular method.

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2. Methods

The laboratory study has been carried out at Lund University from Oct 2022 – March 2023 by 60 subjects with an age varying from 20 - 75 yrs. The subjects have evaluated the perceived subjective degree of discomfort glare from five different lighting systems all providing 500 lux at the task area while having different amount of light on wall and ceiling providing a mean ambient illuminance of the space from 100 to 350 lux. The subjects have evaluated the perceived discomfort glare sensation from the different lighting systems using two nine-degree scales from De Boer and Hopkinson. The light intensity from the different lighting systems was evaluated by the subjects from the Geerdinck six-degree scale. The subjects visual comfort have been evaluated by a four-item scale developed by Suk. All lighting systems were evaluated by the subjects in a laboratory environment without daylight penetration.

The subjects have evaluated the perceived subjective degree of discomfort glare from five different lighting systems all providing 500 lux at the task area while having different amount of ambient illuminance of the space from 100 to 350 lux. (CCT 3000K and CRI ≥80). One lighting system (LS1) provided localized (direct and indirect) lighting using a suspended LED luminaire as well as ambient lighting by wall washers. The remaining four lighting systems provided general lighting having different levels of ambient light. Three lighting systems (LS2, LS4, and LS5) provided direct lighting whereas one lighting system (LS3) provided both direct and indirect lighting. Lighting system (LS2) used ceiling mounted LED luminaires with opal diffusor whereas lighting system (LS3) used suspended LED luminaires with opal diffusor. Lighting system (LS4) used recessed downlights. Lighting system (LS5) used recessed downlights of the same type as LS4 and wall washers to provide additional ambient lighting provided.

The length of the experiment room was six metres (front wall), the width was four metres (side walls), and the ceiling height was 2.70 metres. The reflectance of the room surfaces was 80% for the ceiling, 60% for the walls, 30% for the floor, and 31% for the desk surface.

Participants' sitting position was 3.25 metres from the front wall, and in the middle between the side walls. The height of participants' eye level was 1.20 metres.

Study design

First, twenty participants took part in experiments only once to test lighting system number one. The remaining participants forty participants took part in the experiments twice. In these experiments, twenty participants compared LS2 and LS3, and the other twenty compared LS4 and LS5. In these repeated studies, daytime of the experiment was divided between two groups. Half of the participants took part in experiments during morning and other half took part during afternoon. Participants also took part in the experiment a second time at the same time as their first visit. For LS4 and LS5, it was also possible to take presentation order into account, meaning half of the group first visited LS4 and half of the group first visited LS5. Before visiting the laboratory, participants were asked to not to consume nicotine and caffeine if it was possible.

Procedure

Before participants entered the test room, they were welcomed to the waiting room with a light providing 500 lux at task area. Participants were asked to fill the form which contained questions for eye dryness, sleep disturbances, expected circadian rhythms, medication status, eye colour, well-being, positive and negative affect, and individual strength. After filling the form, participants had an eye vision test. Whole procedure in the waiting room took 20-30 minutes total. Then, they were welcomed to the test room which was designed as an office room with a desk and chair. Before evaluating the lighting systems, participants performed visual tasks that required to read numbers and words that were attached on the walls and write it on a presented paper. The total procedure took maximum one and half hours.

3. Results

Preliminary results will be presented at the conference.

4. Conclusions

Pre-calculations show that the light distribution, positioning as well as size and brightness of room has a major impact on discomfort glare. The impact of glare from the different lighting systems has been subjectively evaluated by the subjects in a stated position and is expected to be influenced by the level of ambient light.

OP51

VISUAL CHARACTERISTICS IN THRE DISCOMFORT GLARE EVALUATION MODEL IN ACCORDANCE WITH THE VISUAL SYSTEM

Hara, N.[1], Takase, K.[1]
[1] Kansai University, Osaka, JAPAN
nhara@kansai-u.ac.jp

1. Introduction

Recently, a model for evaluating discomfort glare has been proposed in accordance with the visual system, which encompasses various visual characteristics from the visual optical system to the viaul nervous system. The model is very complex and evaluation is not easy. In addition, it is a problem that the visual characteristics included in the model have not been sufficiently examined to determine whether they are suitable for the evaluation of discomfort glare.

The visual characteristics of the observer, which are collected by various methods, such as scattering characteristics of the ocular optical system, areas of the receptive field of the visual nervous system, and differences in sensitivity characteristics in central and peripheral vision, may depend on the observation environment of the experiment and the object of observation at the time the characteristics are acquired. The evaluation on which the discomfort glare indicator specified to evaluate general environmental performance should be based is not an evaluation with the viewpoint completely fixed, nor with the luminaire viewed directly. The visual characteristics that should be incorporated into that evaluation index should be appropriately reflected in the evaluation index after a thorough examination of the experimental environment in which the characteristics were obtained. For the purpose of designing real environments based on the evaluations of people with various visual characteristics, such as the use in the design of discomfort glare indicators, it is considered necessary to understand the visual characteristics of people according to the situation in which the problematic phenomenon occurs in the real environment, the observation conditions, and the objects to be observed.

In this paper, we report on the experiments we conducted to identify visual characteristics and the visual characteristics we identified in the process of constructing a discomfort glare evaluation model composed of the main factors reported in a different paper.

2. Subjective evaluation experiment.

This paper reports a subjective evaluation experiment to determine BCD luminance, which was conducted systematically using light source luminance, solid angle, eccentricity angle, and background luminance as variables, to obtain the relationship between light source solid angle and BCD luminance.

The experiment was conducted in a spherical space with a diameter of 2500 mm and no outside light. The subjects observed the glare light source from the center of the sphere through an aperture in the sphere's inner surface. The lighting in the sphere and the glare light source were LED light sources that could be dimmed by PWM control. The surface of the sphere, which was the background luminance, was controlled so that it remained constant even if the luminance of the glare light source was changed, and was set at three levels: 0.3, 3.0, and 34.26 [cd/m2]. The source solid angle was controlled by the aperture size of the inner surface, and was set at five levels: 0.00001, 0.000038, 0.00014, 0.00053, and 0.002 [sr]. The eccentricity was set at four levels: 0[°] for central viewing, where the subjects looked directly at the light source, and 8, 15, and 30[°] for peripheral viewing, where the subjects gazed at a point placed vertically downward from the light source. Subjects adapted to the background luminance and observed the glare light source while fixating on the gazing point indicated by the experimenter. During this time, the luminance of the glare source continued to increase at a constant rate, and subjects reported when they began to feel uncomfortable with the glare of the light source, and this luminance was defined as the BCD luminance.

BCD luminance was lower in regions where the solid angle of the light source was small as its solid angle increased, and was constant in regions where the solid angle was large, even as the solid angle increased. In addition, the larger the eccentricity angle and the higher the background luminance, the higher the BCD luminance.

3. Derivation of visual characteristics based on BCD luminance estimation model

The discomfort glare evaluation model reported in another paper predicts BCD luminance based on the light scattering characteristics of the ocular optical system, the receptive field area of the visual nervous system, and sensitivity characteristics in central and peripheral vision. These visual characteristic values are identified by deriving visual characteristic values that approximate the same relationship obtained by the model from the relationships obtained in subjective evaluation experiments.

The BCD luminance estimated by the discomfort glare evaluation model was confirmed to have a certain degree of conformity to the BCD luminance in the experiment. The visual characteristics derived to ensure conformity were confirmed as follows: the larger the eccentricity angle, the more easily the ocular optics scatters, the larger the receptive field size, and the lower the sensitivity. There was no significant difference in scattering and receptive field characteristics between subjects skilled and unskilled in the discomfort glare evaluation experiment, but the relationship between eccentricity angle and sensitivity resulted in higher sensitivity for the skilled subjects. However, the variation in BCD luminance of the unskilled subjects was large, while that of the skilled subjects was small. We believe that the data from a small number of skilled subjects is useful to examine the structure of the discomfort glare evaluation model, and that the accumulation of data from a large number of unskilled subjects is necessary to obtain data to define evaluation criteria.

4. Conclusions

The scattering characteristics of the ocular optical system, areas of the receptive field of the visual nervous system, and sensitivity characteristics in central and peripheral vision were identified by subjective evaluation experiments as influencing factors in the discomfort glare evaluation model. Since this subjective evaluation experiment was conducted only with younger subjects, there were no significant individual differences in scattering characteristics, but it is expected that scattering characteristics would be different for older subjects. By conducting similar experiments on different groups of evaluators with different visual characteristic values and accumulating data, we can expect to be able to estimate BCD luminance for a wide variety of subjects.

OP88

DISCOMFORT FROM GLARE: WHY WE NEED A CIE TECHNICAL COMMITTEE TO REPORT ON BEST PRACTISE FOR COMMONLY USED METHODS AND TO PROPOSE NEW METHODS

Fotios, S.[1]
[1] University of Sheffield, Sheffield, UK.
steve.fotios@sheffield.ac.uk

Abstract

Reliable prediction of discomfort from glare is proving to be an elusive ambition. The sensation can be defined, and when discomfort is experienced it is known, but despite many studies over many years there is still no authoritative consensus as to how to predict discomfort from glare. This presentation will discuss some of the causes of the mixed results found in experiments.

Kent et al reported three significantly different ($p<0,01$, moderate effect size) estimates of mean glare source luminance for discomfort at each of their four thresholds. For level 3 (for example) these were 3 173 cd/m^2, 3 731 cd/m^2 and 4 475 cd/m^2. The experimental conditions used in the trials leading to these three estimates were identical apart from one aspect: an adjustment task was used and for each estimate the upper luminance that could be set using the adjustment control varied, from 5 106 cd/m^2 to 7 288 cd/m^2 and 9 469 cd/m^2. That result tells us that the experimenter's choice of stimulus magnitudes set at the upper limit of the dimming scale has a significant influence on the outcome. Light level adjustment is a commonly used procedure in studies of discomfort from glare but in few (if any) of these is there any consideration given to the choice of luminance range. Had an experimenter chosen instead a different luminance range, the results from Kent et al suggest they would have reached different results, and hence different estimates of the luminances for different thresholds of discomfort sensation and/or a different model characterising the sensation between lighting parameters and discomfort.

Another commonly-used procedure is category rating. After observing a scene, the test participant is asked to express the magnitude of discomfort experienced by ticking one of a series of points along a scale. Without careful planning, the apparent ease of preparation with this method belies the likelihood of introducing error. One concern is the labelling of stimulus magnitudes along the response scale. Consider the 9-point scale commonly referred to as a 'de Boer' scale. In that scale, magnitude labels are added to the odd-numbered points, and these tend to be along the lines of (from lowest to highest discomfort sensation) just noticeable, satisfactory, just permissible, disturbing, and unbearable. One problem is that the minimum discomfort magnitude that can be recorded is 'just noticeable': the observer is not given the option of stating that discomfort is not at all apparent. A second problem is that the meanings of the lower three sensations are not widely understood by naive respondents, either in the absolute or relative sense. Finally there is no consensus amongst researchers as to where the comfort:discomfort border lies. Hickcox et al proposed a two-step response in an attempt to overcome these issues. Participants are first asked whether or not they experience discomfort, with a response of either Yes or No permitted, and only if they respond Yes are they asked to describe the amount of discomfort using a 6-point scale. The magnitude labels on this scale are easier to understand – the end points were labelled 'very small amount' and 'very large amount' in the given example. This method gives two sets of data for analysis of discomfort (% Yes and rating magnitude), the % Yes response provides a more direct measure for setting absolute thresholds, and a comparison of the two gives some measure of attentivity. The two-step response scale appears to offer advantage but requires validation.

Instead of using subjective evaluation to characterise the degree of discomfort, others have used physiological measures such as changes in pupil size, electrograms and gaze behaviour. However, the analysis tends to be a correlation of these measures against parallel self-report measures: while that tells us whether the two measures are correlated, it still says nothing

about absolute thresholds of discomfort. To establish absolute thresholds of discomfort from glare will require a measure that reveals the threshold by a specific change in response. One possibility is the measurement of eye lid movement: while the upper lid gradually lowers as spatial brightness increases, under extremely bright conditions, as might be associated with disturbing glare, the lower lid moves up to produce a squinting reaction. Establishing the point at which the lower eye lid moves upward may provide an estimate of the absolute threshold for discomfort. Other possibilities are behavioural observation: for outdoor lighting this might be the glare source luminance at which pedestrians start to shield their eyes, or look downwards, or cross the street.

The author proposes to establish a technical committee within the CIE to report on the psychophysical methods used in research of discomfort from glare. Following the format of CIE 212:2014 this report would summarise the commonly used procedures, present evidence of the outcomes of changes in experimental design, and make recommendations for good practise. By drawing attention to differences in experimental design, the aim is not to suggest that any one experimenter was incorrect, but instead to suggest that insufficient attention has been given to researcher degrees of freedom. In addition, the report would discuss physiological and behavioural methods to draw attention to these. Unless action such as this is taken, it is likely that reliable prediction of discomfort from glare will remain elusive.

Session PA8-2
D1/D3 - Indoor lighting

Wednesday, September 20, 14:30–16:05

OP50

A STUDY OF THE PSYCHOLOGICAL GAIN OF ARTIFICIAL VIEW WINDOWS IN A WINDOWLESS SPACE

Hao, X.Y.[1], Zhang, X.[1], Wang, J.W.[1]
[1] Tsinghua University, Beijing, CHINA
haoxy15@163.com

Abstract

1. Motivation, specific objective

Recently, the scale of underground space has grown rapidly, and the types of utilization are abundant. By the end of 2020, China's urban underground space accumulated 2.4 billion square meters, and the underground space added 259 million square meters of building area in 2020, accounting for 22% of the completed urban building area in the same period. However, the current underground spaces still suffer from low efficiency, lagging development function, and low quality internal space. With the accelerated urbanization process, the development of underground space has become an important means to alleviate space pressure, and the potential for application to daily functions such as residence and office is huge. However, how to provide suitable lighting in windowless spaces has been a topic of concern for scholars.

Natural light exposure is beneficial for rhythmic health and has been widely shown to enhance office workers' comfort, wakefulness, and mood, with significant positive effects on sleep quality. Natural light with a view can improve memory and relieve stress, with positive physiological and psychological effects. However, when people stay in an underground windowless environment for a long time during the day, isolation from external stimulus information such as natural light and view can have negative effects such as rhythm disturbances, psychological problems, and cognitive decline. Although above-ground space experiments have quantified the positive effects of lighting (including view) on maintaining rhythm and mood, artificial view and fake windows have been less studied in the field of underground engineering, and the expected healing effects are difficult to achieve.

Currently, images and videos are alternative means of real view; artificial view windows are mostly used in underground commercial spaces, nursing wards, and other windowless spaces to provide visual stimulation and relieve tension. In such spaces, people are usually far from the window or do not need to stay for a long time, so the simulation and comfort requirements are not high. There have been studies on the window view mostly based on the real view, focusing on the content and the spatial occupation ratio, and a lack of research on the luminosity and chromaticity information of the screen presenting the view, which is important for the psychological simulation and environmental cognitive ability enhancement of the artificial view. The lighting performances of the artificial view and the real window also have a large difference. The simulation degree and visual comfort enhancement techniques of artificial view windows need to be improved.

The research objectives of this manuscript are to improve the simulation of artificial view in a daily-scale windowless environment through image content preference and optical performance design of artificial view windows and to improve the psychological gain through the implantation of environmental cognitive information such as orientation and time, so as to enhance the livability and availability of underground space and alleviate the development pressure and carbon reduction pressure of urban space. Meanwhile, the combination of fake window technology and space design can promote the integration of physical and virtual interfaces, realize augmented reality-based place interaction, and build a future-oriented smart city space scene.

2. Methods

Collect all types of real-view images, including still pictures and dynamic videos, and complete the initial selection through pre-experiments. Place the initial images on the screen in the evaluation laboratory, obtain the preferred images through the field evaluation experiment, and classify them to establish the artificial view image database. Record the illuminance and spectrum of environment, desktop, and eye provided by each view image through the screen and improve the photometric parameters of each image in the database.

For the preferred artificial view images, dimming devices such as curtains and adjustable louvers are set to enhance interactivity, and the fake window construction method is completed in the laboratory for the purpose of improving reality. Using the underground office as a prototype, the intelligent lighting system on top of the room is set to ensure that the rhythmic and task lighting between groups are the same and conform to the natural light pattern. Participants completed different types of behavioral tasks in real-life situations during typical office hours (morning, afternoon, and night). Through physiological monitoring by human factors equipment and psychological gain measurement by combining visual tasks and subjective evaluations, inter-group comparison experiments are completed on the content settings, photometric parameters, and construction practices of artificial view windows.

3. Results

By collecting participants' physiological data such as galvanic skin response and heart rate and analyzing the evaluation results of PAD, PANAS, KSS, SAS, and other questionnaire scales in terms of mood, anxiety, and arousal, the following conclusions were drawn: the artificial view window has a positive physiological-psychological effect on the participants in the windowless space, relieves tension, enhances satisfaction and work interest, and the dynamic video has a better psychological gain compared to the still image. Different types of artificial view (natural and urban) have different psychological gains for participants, and there is an interaction between the photometric parameters of the artificial window and the participants' behavioral tasks.

4. Conclusions

This study summarizes the quantitative discriminative method of artificial view on mental gain through experiments and summarizes the expression of photometric properties of artificial view. And according to the results, it summarizes the application to the windowless space in line with the rhythmic demand and the environmental cognitive artificial view window design method. Detailed reference recommendations for image content, photometric parameters, and construction practices for artificial windows are provided. The results can improve the reality and comfort of artificial view windows and guide the design of habitat-oriented underground space lighting.

OP27

50 YEARS LATER: EXTENDING THE WORK OF JOHN FLYNN AND CIE STUDY - GROUP A

Bernecker, C.A.
The Lighting Education Institute/Exton, PA, U.S.A.
Parsons School of Design, The New School, New York, NY, U.S.A.
berneckc@newschool.edu

Abstract

1. Motivation, specific objective

This paper presents two studies that follow on the work of the1973 CIE Study Group A, led by John Flynn, exploring the influence of light on subjective impressions of an environment. In particular, one study focuses on chromaticity, i.e., color temperature, as one of the parameters, followed by a second study that incorporates light level, i.e., illuminance, along with chromaticity as two of the parameters that might influence these subjective impressions.

In the arc of Flynn's work, he identified both subjective impressions that can be influenced by lighted environments and the characteristics of a lighted environment that can elicit these impressions. The characteristics of a lighted environment, or "lighting modes" as he called them, include overhead (vs. peripheral) lighting, uniform (vs. non-uniform) lighting, bright (vs. dim) lighting, and visually warm (vs. visually cool) lighting.

In most summaries of Flynn's work, the fourth mode, visually warm vs. visually cool, is not evident. This is because this mode was the weakest of the four lighting modes, and Flynn himself identified that this characteristic of a lighted environment required further study. One of the limiting aspects of the study of this lighting mode was the lack of availability of a wide range of color temperatures of light sources available to manipulate as an independent variable in the study of the influence of the visually warm/visually cool mode on subjective impressions. Flynn had warm white and cool white fluorescents, along with incandescent and/or halogen sources, quartz metal halide, and high-pressure sodium to light the test environments. Flynn's studies were not only limited by the few color temperatures to test, but also by their limited color rendering abilities.

Today's availability of solid-state lighting (LED) sources provides a much wider array of light source colors of almost limitless steps in color temperature, while maintaining good color rendering across those steps. Thus, there is a significant opportunity to revisit Flynn's work to determine just how much an influence light source color might have on subjective impressions of architectural environments.

2. Methods

The first study explores variations in color temperature, i.e., the visually warm vs. visually cool mode, while holding the other three constant. The second study adds illuminance, i.e., the bright-dim mode, while holding the remaining two modes constant (overhead-peripheral and uniform-non-uniform).

In both studies, the test space was an approximately 20' x 20' x 10' classroom with fairly neutral finishes throughout. Two, twelve-foot long suspended direct/indirect tuneable white luminaires in two rows were installed in the space. Both the direct and indirect components had separate dimming and color temperature controls, allowing the tuning of color temperature and intensity of light. The test conditions were 2700K, 3000K, 3500K, 4000K, 5000K, and 6000K, while illuminances of 25, 50, and 75 foot-candles were delivered at the

center of the room (study two) with less than a 2:1 ratio between the maximum and minimum illuminances. The luminances of the ceiling and walls were quite uniform, holding overhead/peripheral and uniform/non-uniform constant.

Forty and thirty-two subjects, respectively, were tested in groups of eight for the two studies. Testing for each study followed the protocol developed and published by Flynn in an attempt to replicate the testing procedure as closely as possible. The first part of the testing consisted of evaluating each color temperature on a series of semantic-differential rating scales (identical to Flynn's S-D scales), while the second consisted of rating the perceived difference between color temperatures on a scale of 1 to 10 through a series of paired comparisons.

3. Results

The results of the first study indicate that chromaticity has a stronger influence on subjective impressions than could be determined by Flynn, particularly impressions of warmth or coolness of an environment, as one might expect, the perceived spaciousness or confinement an environment, and the perceived behavioral setting (public-private). Additionally, the results suggest that all six color temperatures were readily distinguishable from one another when presented randomly in a sequentially paired comparison.

In the second study there were some nuanced differences on the visually warm-visually cool scale. For example, at 75 foot-candles, the visually warm-visually cool ratings tend to shift toward visually cool when compared to the other illuminances, while at 50 foot-candles they tend to be more centered. At 25 foot-candles, the visually warm-visually cool ratings were more extreme than for the other illuminances.

On the clear-hazy scale, the ratings tend to cluster at clear for all color temperatures at 75 footcandles, while at 50 foot-candles, the ratings tend to cluster in the mid-to-high range of color temperatures with more overlap. At 25 foot-candles, the ratings again tend to cluster more midrange, but both high and low color temperatures were rated more hazy than the middle color temperatures.

For the public-private scale, the ratings at 75 foot-candles tend to show public is more associated with high color temperatures and private with low color temperatures. At 50 foot-candles, the ratings cluster more at the mid-range color temperatures, while at 25 foot-candles, the ratings shift toward the private end of the scale.

For the like-dislike and pleasant-unpleasant scales, very high and low CCT's were more disliked or unpleasant. This is similar for the 50 footcandle ratings although not quite as extreme. At 25 foot-candles, the ratings tend to cluster more, and low color temperatures are more acceptable.

4. Conclusions

In the first study it was concluded that the data showed a strong influence of color temperature on several impressions consistent with Flynn's other modes, such as public-private, clear-hazy, and spaciousness-confinement. In the second study, the data suggests this is not entirely consistent with changes in illuminance level. In some case one can clearly begin to see that illuminance level has a more dominant influence than color temperature. At the same time, the influence of color temperature can be seen as a much stronger factor than was shown in the original Flynn research, and indeed that there is a fourth lighting "mode," the visually warm-visually cool mode that influences subjective impressions in the built environment.

It is also clear that there is an interaction between color temperature and illuminance level, and suggest this interaction requires further exploration. The interaction between these two modes suggests the need for further study that includes all four modes - bright-dim, visually warm-visually cool, overhead-peripheral, and uniform-non-uniform, along with their definition.

OP43

PHOTOMETRIC, PSYCHOLOGICAL AND NEUROPHYSIOLOGICAL ASPECTS OF DIFFERENCES SEATING LOCATIONS IN SELF-STUDY ROOM

Cui, S.Y.[1], Zhang, X.[1],
[1] Tsinghua University, Beijing, CHINA
18801158987@163.com

Abstract

1. Motivation, specific objective

Previous studies have demonstrated that the spectrum, quantity, direction, time, duration, and other characteristics of light have an impact on the emotional and physiological state of personnel, as well as on cognitive processes such as memory and attention. However, in prolonged self-study situations, the dynamic changes in natural light and the adjustment of artificial lighting lead to complex and synergistic changes in the spectrum, quantity, and other characteristics of light, which are significantly different from controlled changes in the laboratory. On the other hand, the work tasks in self-study situations are visual task-based mental work, controlled and coordinated by the nervous system physiologically and psychologically. That is, cognitive performance is influenced by emotional and physiological states, which is more complex in prolonged situations. In dynamic self-study situations, the combined effects of different combinations of light spectrum, quantity and other factors formed on the cognitive performance, emotional and physiological state are not yet known.

Research findings in the field of neurophysiology can explain how human perception of the world affects cognitive processes and physiological and psychological states. Based on a neuroarchitecture perspective, this study establishes a link between the cognitive performance, environmental evaluation, emotion, and physiological state and the quantity of light, non-visual exposure stimuli, and other characteristics by constructing a natural experiment of prolonged self-study. Understanding the characteristics of the luminous environment from a neurophysiological perspective, the results of the study can guide the intelligent lighting design of learning spaces.

2. Methods

Self-study behaviours are characterized by time-consuming, dynamic daylight mixed with static electric light, and multiple people co-located in the same space. In this study, a 14-day natural experiment was conducted on 12 positions in a north-facing classroom with intelligent lighting, where the luminance and colour temperature of each luminaire corresponding to the location could be adjusted independently. During the experiment, the 12 positions were kept full, and multiple people were restored to study at the same time, and the space felt close to the real situation. Participants were required to study independently for 3.5 hours in the morning and 3.5 hours in the afternoon at the same location. The long-time natural experiment ensured that the non-visual cumulative effect of time played its full role, and the experimental data better reflected the real self-study state.

Multiple instruments were used to collect multidimensional human factor data from subjects. The Karolinska Sleepiness Scale, Pleasure-Arousal-Dominance Emotional-State Scale and Visual Comfort Rating Scale were used to assess the subjects' wakefulness, emotion and subjective environment. Stroop, Go-NoGo, equation calculation and N-Back were used to measure cognitive performance such as concentration, perception, logical reasoning, and memory. Wireless human factor physiological recorders and smart wearable sensors were used to collect physiological data such as electrocardiogram (ECG) and electrodermal (EDA).

The original variables of multidimensional human factor data were downscaled by principal component analysis and factor analysis to construct personnel learning state evaluation factors. Based on the three dimensions learning state evaluation factors, including cognitive performance, subjective evaluation, and physiological state, the K-medoids method was used

to cluster the data of each location at different time periods and different combinations of electric lighting and daylight. Multiple clusters were obtained and the photometric characteristics of the luminous environment under each cluster were extracted and associated with multidimensional learning state.

3. Results

Based on principal component analysis and factor analysis, eight learning state evaluation factors were constructed, including "sustained attention", "working memory capacity", "environmental satisfaction", "subjective arousal", "contextual influence", "autonomic coordination", "sympathetic activity" and "parasympathetic activity". A total of 84 personnel status data were clustered by K- medoids method for each location of different experimental dates and time periods. Based on this, the luminous environments and personnel states at each location were clustered into 2, 3, 8, 9, and 10 clusters, respectively.

There was a strong similarity of photometric features including illumination and non-visual stimuli within clusters at each location, and there were significant differences between different clusters, which were also expressed in the time dimension. In addition, there was also strong similarity in the cognitive performance, subjective evaluation and physiological state of the personnel within each cluster, while there were significant differences between clusters. For example, at the luminous environment level in some clusters, cognitive performance and subjective evaluation of personnel were good but sympathetic and parasympathetic activity was weak, while in other clusters, cognitive performance and subjective evaluation of personnel were at moderate levels but sympathetic and parasympathetic activity was strong.

4. Conclusions

The study shows that it is possible to categorize different combinations of electric lighting and daylight from a neurophysiological perspective and to establish a link between the photometric characteristics and the multidimensional learning state. The effects of different combinations of electric lighting and daylight within the same cluster on personnel multidimensional learning factors are similar, and these combinations also have similar photometric features, while they tend to differ significantly between clusters. The illuminous environment clustering is not the same across positions, which may be influenced by the variability of the view and psychological attributes across positions, such as privacy. Under the effect of environmental factors, personnel cognitive performance, subjective evaluation and physiological state interact with each other, and the multidimensional indicators help us to explore the potential association between environmental factors such as light and personnel state, and then guide the design to improve personnel physiological and psychological state and enhance cognitive performance.

OP85

ATMOSPHERE DECIPHERED: LUMINANCE CONTRAST MEASURE FOR LIGHTING DESIGN

Yalçın, I.[1], Olguntürk, N.[1]
[1] Bilkent University, Ankara, TURKEY,
i.yalcin@bilkent.edu.tr

Abstract

1. Motivation, specific objective

Imagine a visual ability enabling you to instantly pick up many clues about your surrounding environment and deduce objective descriptions. Our visual system operates similarly and sometimes deviates as optical illusions. Yet, at first glance, we can also perceive a space as impressive, exciting, spacious, intimate or depressing, uncomfortable, confined, or insincere. This ability is currently studied under the name "atmosphere", and recent debates about this topic manifest light as one of the dominant factors in generating atmospheres.

In the field of lighting research, the quality of lit environments has been under several examinations for impressions of light and ambience studies based on quantitative measures. However, such light effects cannot be understood by isolated observations of how light interacts with and reflects on surfaces composed of various substances in the environment. Here, we propose an alternative utilisation of contrast measurements for lighting design. Contrast is essential as it allows one to differentiate between items or differences in the field of vision, whether real or virtual, representations of the built environment. In this preliminary investigation, the luminance contrast of images was examined as a comprehensive technique to analyse how light in a scene affects its atmosphere.

2. Methods

The main parameters of this study were luminance contrast and perceived atmosphere adjectives related to lit environments. Intended to extract information from architectural images, Spatial Luminance Contrast determines the variance between adjacent pixels. A local contrast value is initially defined and used in a pyramidal structure. These values are employed once more to define the following value for a step up the pyramid. The fifth level was determined to be consistent in response to a range of subjective judgments. Hence, this work computed the monitor luminance of pixel contrast for the experimental images using this measure as a potential indicator of atmosphere evaluations.

Initially, a collection of images was created using various natural and artificial light sources, outdoor and interior scenes, and different geometric and material compositions to depict the multitude of stimuli prevalent in modern-day living. After that, fifty-four Turkish atmosphere adjectives were developed by a systematic collection, translation, and reduction of adjectives used in lighting research to characterise the impressions, quality, and atmosphere of lit environments. These adjectives were used to generate an atmosphere scale for rating experimental images.

3. Results

The findings of the Principal Component Analysis revealed three components, the first two of which were connected to the luminance contrast of experimental stimuli. These were

described as the effects of spatial feature/material attributes and luminous properties of an environment.

Overall, the images with greater luminance contrast and low brightness levels intensified the negative atmosphere descriptions. For example, matte, blurry, subdued, and dark definitions were reinforced with low ambient light and higher contrast environments over the spatial feature/material attribute component. Descriptions of an artificial, dull, dim atmosphere were observed in the same environment for the component of luminous properties.

Atmosphere descriptions with positive connotations were observed when low luminance contrast levels matched with high average brightness in images. These were exciting, lively, and transparent for spatial feature/material attributes component and spacious, natural, and impressive for the component of luminous properties.

4. Conclusions

Two components recovered from the PCA of atmospheric adjectives were an environment's spatial aspects/ material properties and luminous properties. These parameters highlight the fact that observed atmospheres are physically constrained. In other words, desired atmospheres could be constructed or reproduced by fine-tuning the luminance contrast of a scene.

This work has also demonstrated atmospheric studies and luminance contrast measures with images of real environments. The exhaustive list of Turkish atmosphere adjectives and their junction with earlier studies provides a foundation for future atmosphere research about light and sensed places.

The results of this study provide insight into the formation and spread of atmospheres in illuminated environments. These will allow us to more accurately explain what was previously felt in the air and develop innovative lighting strategies that match desired features as atmospheres in related disciplines of the built environment, architectural lighting, visualisations, and atmosphere research.

OP9

A CORE LIGHTING CURRICULUM FOR UNIVERSITY STUDENTS

Houser, K.W.[1]
[1] Oregon State University, Corvallis, USA
kevin.houser@oregonstate.edu

Abstract

In collaboration with a group of lighting professionals, learning outcomes were defined, prioritized, organized, and mapped to a three-course sequence of Architectural Engineering (ARE) courses at Oregon State University. Syllabi and educational exercises were developed to support the learning outcomes—including classroom activities, homework assignments, and design projects. The exercises balance fundamentals with applications and are intended to promote significant and lasting learning by providing students with realistic, contemporary, and contextual educational experiences. The course sequence and learning content balance the technical foundations of applied illuminating engineering with the artistic aspects of applied lighting design. Herein the process for identifying and prioritizing lighting content is described, a process that could be adapted to other pedagogical contexts. The syllabi and learning exercises are freely disseminated for reuse or adaptation by other lighting educators, or for self-study by independent learners.

1. Motivation, specific objective

This curriculum development project, which received support from the Nuckolls Fund for Lighting Education, was conceptualized as a catalyst for three primary outcomes. First, as an impetus to cement lighting education in the Bachelor of Science in Architectural Engineering program at Oregon State University. Second, to support the needs of the professional community by inspiring students to pursue careers in lighting, while building intellectual capacity in the art and science of applied lighting. Third, to collegially disseminate the learning materials in a format that can be adapted and reused by other lighting educators.

Full-time lighting educators and researchers may be partially insulated from the practical problems faced by designers when designing and specifying lighting equipment for the built environment. Applied lighting is in a transformative period. What was once an analog technology, is now solid state. Project timelines often make conventional design-bid-build impractical. Software for architectural modeling and lighting design is ever evolving. Control technologies are rapidly changing. As lighting professionals become increasingly aware of how light affects physiology, the impact of light on health has become an increasingly important matter for design. While designing lighting for people, professionals must also consider the sustainability of planet earth, including collateral impacts on flora and fauna. Programs like LEED, WELL, Energy Star, Design Lights Consortium (DLC), and others now influence design goals and equipment selections. Fundamental concepts in lighting design and illuminating engineering are largely unchanged, but the contemporary context is rapidly evolving. The practice of lighting design and lighting education must adapt to new technologies and knowledge, including a deeper understanding of how light affects health, an increased sensitivity to sustainability goals, and increased awareness of ecological consequences of lighting design decisions. It is not obvious how such matters should be prioritized when developing or revising a curriculum about lighting for the built environment. This project was conceptualized with the belief that collaboration that provides informed counsel from a broad group of lighting professionals would more likely lead to good curricular outcomes.

This curriculum development project included close collaboration with five highly-regarded lighting professionals—Teal Brogden (Horton Lees Brogden Lighting Design), Jason Edling (Niteo), Sean O'Connor (Sean O'Connor Lighting Design), Charles Stone (Fisher Marantz Stone), and Andrea Wilkerson (Pacific Northwest National Laboratory). In generously sharing their expertise, they offered the viewpoints of hiring authorities, business owners, designers, and women engineers. They shared opinions about design processes, technologies, fundamentals, and applications, all in support of developing a credible curriculum.

3. Results

A three-quarter (one academic year) sequence of courses was developed, with course descriptions as summarized below.

ARE 361—Fundamentals for Lighting Design: Demonstrate critical thinking about illuminating engineering and applied lighting in the built environment. Explore lighting terminology, photometric quantities and units, the visual response of the human eye and brain, luminous radiative transfer, lighting equipment, elementary lighting design procedures, and basic lighting calculations.

ARE 461—Lighting Design for the Built Environment I: Builds upon ARE 361 to advance critical skills in illuminating engineering and applied lighting for the built environment, emphasizing integration between the lighting design process, technical fundamentals, and application to design. Extends depth in photometry by calculating illuminance with diffuse radiative transfer. Establishes design criteria, employs computer-based calculations as a verification tool, and creates solutions compliant with compulsory standards.

ARE 462—Lighting Design for the Built Environment II: Builds upon ARE 461, extending lighting design skills and technical knowledge in applied illuminating engineering to produce defensible solutions to open ended engineering problems. Prioritize and balance competing criteria that addresses lighting requirements for the visual experience (e.g., vision, visual comfort, psychological reinforcement, color quality) and human health, while accounting for energy use and complying with compulsory standards. Demonstrate facility with the lighting design process, luminaire photometry, applied colorimetry, and software-based simulation.

Course learning outcomes were developed for each course and mapped to the Accrediting Body for Engineering and Technology (ABET) required student learning outcomes. Learning exercises were developed, with a method to longitudinally track student performance relative to achievement of the defined learning outcomes. A webpage was developed to enable other educators to access the materials developed. The presentation will share these processes, outcomes, and resources.

4. Conclusions

While the lighting curriculum development activities described in this work were developed within the context of Oregon State University's Bachelor of Science in Architectural Engineering degree program, both the process and outcomes are readily adaptable to other educational contexts. In disseminating this work, the goal is to support other educators in our shared objective of offering relevant, contextualized, and rigorous lighting education programs that support student academic development, career readiness, and the advancement of lighting as a profession.

Session PA8-3
D4 - Outdoor integrative lighting
Wednesday, September 20, 14:30–16:05

OP7

DO FEMALE PEDESTRIANS EXPRESS A LOWER DEGREE OF REASSURANCE THAN MALE PEDESTRIANS? AND DOES ROAD LIGHTING HELP?

Mao, Y.[1], Fotios, S.[1], Uttley, J.[1], **Gorjimahlabani, S.**[1]
[1] University of Sheffield, Sheffield, UK
steve.fotios@sheffield.ac.uk

Abstract

1. Motivation, specific objective

Road lighting is assumed to influence pedestrian reassurance – the confidence to walk alone after dark. Increased reassurance is linked to greater levels of walking. In response to physical assaults on female pedestrians, one government response is to spend money on road lighting with the assumption that females in particular will feel safer. Does this work?

When measured using self-report, previous studies comparing responses in daytime and nighttime tend to conclude that female pedestrians feel less safe than males when outside and in public spaces. Furthermore, while darkness reduces feelings of reassurance in both males and females compared to their experience in daylight, the reduction is larger for females. A limitation of some such studies is that it is not known at what time of day respondents gave their evaluations: it is possible that responding in daytime about fear of walking in the dark (a perceived perception) may exaggerate or underestimate the degree of fear compared with an evaluation made after dark (the direct perception).

A second method of measurement is to observe the number of people walking in daylight and darkness. This might be considered as a revealed preference (what people do) rather than the stated preference of self-report (what people say they do). A travel count study using on-road observation to record the age and gender of passers-by (pedestrians and cyclists) found that darkness had a significantly greater deterrence on female cyclists than on male cyclists but did not suggest a significant difference between male and female pedestrians, in direct opposition to the expectation from the results of self-report studies.

A further question is whether changes in road lighting affects the disparity in reassurance between males and females. In self-report studies of pedestrian reassurance from the lighting research domain, the sample tends to be balanced for gender to promote population representation rather than testing hypotheses about male and female responses. In those studies where responses were analysed by gender the results show that females tended to express a greater degree of fear than did males. But while these studies tended to include areas of different light levels, they have not tested the degree to which higher light levels alleviate the differences between male and female feelings of reassurance.

We report an analysis of gender differences in two pedestrian reassurance field studies: the first was conducted in the autumn and spring clock change periods of September 2021 and March 2022, and the second is being conducted in February-March 2023. The results will be used to test for an expected difference in male and female reports of reassurance and extend previous work by testing whether this difference changes with illuminance.

2. Methods

Pedestrian reassurance was evaluated using the day-dark method in which perceived safety is evaluated in daylight and after dark and the difference between these two evaluations is used as a measure of the effectiveness of road lighting. The first experiment recruited 60 participants to evaluate 6 locations. The second experiment recruited 140 participants to evaluate a different selection of 12 locations. The locations were chosen to give variation in light level and experimenter-predicted feelings of safety.

3. Results

Results from the first experiment show that females reported significantly lower levels of reassurance than did males ($p=0.014$). Males and females both gave lower reassurance ratings after dark than during daylight, and this difference between daylight and after-dark reassurance ratings was greater for females than males ($p=0.023$). The second experiment will end in March 2023. Results from the two experiments will be analysed using a linear mixed effects model to compare the effect of light level on the difference between male and female responses.

OP47

ROAD LIGHTING IMPACT ON PEDESTRIAN ALERTNESS: TESTING THE NULL FINDING OF GIBBONS AND BHAGAVATHULA

Alshdaifat, A.A., Fotios, S.
University of Sheffield, Sheffield, UK
a.alshdaifat@sheffield.ac.uk

Abstract

1. Motivation, specific objective

In two experiments, Gibbons et al 2022 and Bhagavathula et al 2021 examined the impact of outdoor lighting on alertness. In Bhagavathula et al 2021 they measured melatonin levels derived from saliva samples, self-report of sleepiness and response to a visual reaction time test whilst driving on a closed loop road under five lighting conditions. In Gibbons et al 2022 they measured melatonin (from saliva samples) in three cohorts of participants, drivers, pedestrians, and those experiencing light trespass in their homes, using six lighting conditions typical of road lighting. Both experiments were conducted in the evening, with light sources and light levels typical of those used for road lighting, giving equivalent daylight illuminances (EDI) of about 0,22 to 5,7 lx.

The results of these experiments did not suggest a significant effect of lighting on reaction time nor melatonin. These measures are a proxy for alertness and their results are surprising given the evidence from other studies that lighting does influence alertness. One possible reason why the work of Gibbons et al and Bhagavathula et al did not reveal an effect is that their EDI was not sufficient, being a maximum of 5,7 lx, a result of their decision to use light sources typical of current road lighting practise. A second reason is that the experiment design was not sufficient to reveal an effect. We therefore conducted an experiment to measure the impact of lighting on reaction time and melatonin levels in the evening but using a much higher EDI to force an effect on alertness if such an effect exists.

2. Methods

This was a laboratory experiment, starting at 21:00, with two participants each evening. The forty participants (median age of 21 years) were first seated for two hours adapting to lighting representing a domestic interior (25 lx, 2700 K, 10,7 lx melanopic EDI). This was followed by exposure for one hour to one of four test lighting conditions. The first lighting condition (L1) provide a vertical illuminance at the eye of 0,5 lx with a CCT of 2700 K and an EDI of 0,5 lx. This was intended to represent very dim outdoor lighting. For the second condition (L2) the illuminance was increased to 8 lx, within the range expected of road lighting, giving an EDI of 3,4 lx. L2 was the same setting as used in the preceding adaptation period. The third condition (L3) provided the same illuminance at the eye as L2 but with the CCT increased to 5800 K, and an EDI of 10,4 lx. The final condition (L4) used the same CCT as L3 but increased the illuminance to 83 lx to provide an EDI of 99 lx. The lighting conditions were thus similar to or higher than the road lighting conditions were used in Gibbons et al and Bhagavathula et al. During the test phase participants walked on a treadmill at moderate speed (mean speed 4,2 km/h) as determined by measurement of heart rate. Two measurements were taken at regular intervals during the three-hour experiment: reaction time to an auditory stimulus and melatonin levels as determined from saliva samples.

3. Results

Across all lighting conditions, the melatonin level displayed the expected gradual increase with time. For lighting condition L4, there was a significant decrease in melatonin during the test phase. Reaction times displayed a learning effect, with the first trial revealing a slower reaction time than subsequent trials. For lighting condition L4 the reaction time was significantly faster during the test phase than during the adaptation phase.

4. Conclusions

These results confirm the findings of Gibbons et al and Bhagavathula et al that changes in road lighting with the range of typical practise do not have significant effect on reaction time and melatonin, measures which provide an indication of alertness. In the current experiment and effect on alertness was found when increasing from an EDI of 10,4 lx to 99 lx: a similar significant effect was found by Gibbons et al and Bhagavathula et al with their control conditions, and such lighting conditions are beyond that which would be considered acceptable or otherwise optimal for road lighting.

OP78

CALCULATION METHOD AND EVALUATION OF POSSIBLE EFFECT ON CIRCADIAN SYSTEM OF DIVERS UNDER TYPICAL STREETLIGHTING CONDITIONS

Schwarcz, P.
Budapest, HUNGARY
ptrschwrcz@gmail.com

Abstract

1. Motivation, specific objective

Ocular light exposure at night can effect on circadian system in humans. At sufficient light levels, all visible light wavelengths can provoke this response, but circadian response is maximally sensitive to visible short wavelength light. With the conversion of streetlighting to solid state sources that have a greater short wavelength spectrum than traditional sources, there is a potential negative health impact through influencing the biological clock of drivers. CIE published a standard about the CIE System for Metrology of Optical Radiation for ipRGC-Influenced Responses to Light, as well as a tutorial and a toolbox about the same topic. Recently, a comprehensive consensus view has been published about recommendations for daytime, evening, and night-time light exposure to best support physiology, sleep, and wakefulness in healthy adults. Based on above scientifically proven sources and using standard streetlighting calculation tools, this paper presents data of melanopic EDI (Equivalent Daylight Illuminance) and their effect on the circadian impact of street lighting on drivers under typical usage pattern.

2. Methods

I performed calculations for typical streetlighting scenarios following relevant CIE recommendations made for visual performance. Typical means in this context that neither average lighting values nor Threshold Increment values exceed the recommended ones. As part of the calculation, I calculated typical values for veiling luminance (vertically at eye level). Those calculations use sensitivity curves valid for high adoption levels for vision, v(λ). For evaluation of the effect on circadian system, I transformed those values to melanopic EDI values for different spectral distributions typically used in streetlighting today. As a result of this method, I received typical melanopic EDI values for streetlighting depending on lighting scenarios and type of light sources.

3. Results

The results obtained by the method above demonstrate: If a streetlighting is designed properly and respect recommendations of relevant CIE publication already established for streetlighting for visual performance, especially glare restrictions, <u>the light provided by streetlighting has no significant harmful effect on circadian behaviour of drivers.</u> Although, the although the melanopic EDI values could slightly differ according to spectral distribution of light sources and lighting levels in normal circumstances, but (in any cases) it remains well below trigger level (10 lux EDI) recommended for the period before going to bed by the consensus view. In other words, ocular light exposure at night by a well-designed streetlighting will not have significant effect on sleeping quality afterwards. This is an important conclusion by several aspects. First of all, i<u>t paves the path for extension of current streetlighting design recommendations by CIE to melanopic evaluations.</u> As an addition, it gives a calculation-based evidence against publicly available “views” about harmful effect of the streetlighting, especially LED based ones on circadian system of humans. This paper

focuses on drivers, but its method could be easily extended to other stakeholders of streetlighting such as pedestrians or residents in neighbourhood.

4. Conclusions

Although results are reassuring, there are limitations of the methods used in this paper. Recommendations for light exposure levels by the consensus view were based on indoor environment, however they were applied for outdoor environment by this paper. The consensus view refers to constant lighting levels, while lighting levels perceived by the drivers in streetlighting situation fluctuate on a magnitude of 1:2,5 due to the continuous movement of the vehicle. Only the effect of streetlighting are considered, the effect of headlamps of the oncoming cars and lightsources from the environment such as billboards are excluded. There are very limited field studies are available for outdoor streetlighting environment regarding the effect on circadian system but those are supporting the result of this paper. Due to the limited number of field tests, further evidence needs to be established.

The results of this paper evaluate the effect of lighting on circadian system via ocular system exclusively. It does not include any possible correlation between any other (than ocular) effect(s) of driving activity before going to bed and physiological or psychological functionality of the brain or nervous system.

OP87

EXPLORING THE RESTORATIVE POTENTIAL OF DAYTIME AND NIGHTTIME SCENERY IN CAMPUS SPACE: PHYSIOLOGICAL, PSYCHOLOGICAL AND BEHAVIOURAL ANALYSIS

Zeng, X.X.[1], Lin, Y. [1], Zhang, B. [1], Chen, S. F. [1]
[1] Tongji University, Shanghai, CHINA
linyi_tjcaup@tongji.edu.cn

Abstract

1. Motivation, specific objective

Due to multiple factors such as heavy academic work, social competition, and interpersonal relationship, more college students have mental health problems. As the main activity space for college students, campus space has an important impact on students' physical and mental health. Light is an important element in shaping the landscape. Under different lighting, the same scene will present different image, thus trigger people's different perceived restoration. However, most studies focused on the restoration effect of daytime landscape. College students can be in campus any time of day, the restoration benefits of night-time landscape under artificial lighting should also be paid more attention to, besides the basic safety requirements.

This research had two main objectives. The primary aim of this study was to investigate the associations between different lighting environment of campus spaces and the perceived restoration. The secondary aim of the research was to explore the correlation of using physiological indicators, self-reports and behavioural outcomes to evaluate perceived restoration.

2. Methods

A pilot study was conducted in a campus to investigate how changes in the light/lighting condition affect students' perceived restoration. We measured physiological and psychological changes among college student participants to evaluate the restorative benefits of the same space under 3 lighting condition. The 3 lighting scenes were day scene (cloudy), night scene A (landscape light + street light), night scene B (street light only). Three self-reports (the Perceived Restorative Scale, Self-Assessment Manikin Scale and Landscape Perception Scale), three physiological measures (EKG, skin conductance response and respiration) and behavioural evaluation (response speed) were used to analyse the effects of different lighting environment on restorative benefits.

3. Results

The qualitative results demonstrated the following: (1) The results of the Perceived Restorative Scale showed that there were certain differences in the perceived restorative power of the 3 lighting scenarios, with the highest level in the night scene A, followed by the day scene and the night scene B. (2) The results of behavioural tests, heart rate variability and the Perceived Restorative Scale all showed that night scene A were beneficial to physiological and psychological restoration, as well as the behavioural performance .(3) Findings revealed consistent results among the behavioural tests, heart rate variability and the Perceived Restorative Scale. In addition to, findings showed consistent results among the Self-Assessment Manikin Scale, Landscape Perception Scale and respiration.

4. Conclusions

This study provides practical evidence for the restorative potential of nightscape. Meanwhile, it also puts forward restorative requirements for improving the lighting design quality of campus space after dark. In the lighting design of campus space, we should not only light up the space for basic safety needs, but also create a comfortable nighttime environment, which is conducive to students' perceived restoration.

OP49

NATURALISTIC ASSESSMENT OF THE IMPACT OF ROADWAY LIGHTING ON MELATONIN

Gibbons, R.B.[1], Bhagavathula, R. [1], Warfield, B. [2], Brainard, G. C. [2], Hanifin, J. P.[2]
[1] Virginia Tech, Blacksburg, VA USA, [2] Thomas Jefferson University, Philadelphia, PA, USA
rgibbons@vtti.vt.edu

1. Motivation, specific objective

With the advent of Solid State Lighting for use in roadway lighting, there has been significant discussion on the impact of the light exposure from these systems on human users of the roadway. While there are positive impacts of lighting in terms of safety and usability, there are also potential negative impacts, particularly on melatonin levels and sleep. Previous research has shown that at sufficient light levels of ocular exposure to light at night can supress melatonin production by the pineal gland across all visible wavelengths but particularly in the short blue wavelengths that are highly prevalent in solid state lighting. This issue of melatonin suppression is critical as it represents the potential for impacts on sleep and health. One of the considerations of the previous research, however, is that the measured melatonin impacts have been determined in laboratory settings at light levels that are often above those experienced in roadway lighting conditions in conditions that are not representative of normal activity. This paper considers two investigations: one considering the impact of light source spectrum on salivary melatonin and the other considering the impact of intensity on salivary melatonin both in a naturalistic environment.

2. Methods

Using the Virginia smart roadways, a closed full scale roadway testing facility with a variable lighting system, two experiments were run. The first experiment considered light source spectrum where 29 healthy participants were recruited and assigned to a cohort as either a pedestrian, driver or light trespass experiment and were asked to perform tasks in the roadway environment while being exposed to five different light sources and a no lighting condition. The second experiment considered light source intensity where 10 participants were recruited to drive a vehicle for two hours under four different light lighting intensities. The exposure sessions in each experiment were separated by a week. The exposure were within the typical range of lighting for roadways as defined by the Illuminating Engineering Society. In the first study, pedestrians were sitting at a table for four hours, light trespass participants were sleeping with 1.5 photopic lux on their pillow in a bedroom beside the roadway for two hours, and drivers drove a vehicle for 2 hours. Salivary melatonin samples were taken every 30 minutes during the exposures. Other metrics were recorded for the divers which included alertness and visual performance.

3. Results

Compared to the no roadway lighting condition the results indicate that the roadway light source spectral content did not significantly suppress salivary melatonin levels in the participants in any of the cohorts. Similarly, the changes in the intensity of the light sources did not induce a change in salivary melatonin. A change in the visual performance over time was seen with the varying lighting levels.

4. Conclusions

These data show that recommended levels of street lighting for expressway roads do not elicit an acute suppression of salivary melatonin and suggest that the health benefit of roadway lighting for traffic safety is not compromised by an acute effect on salivary melatonin. In comparison to previous research, this indicates that while there is no salivary melatonin impact at typical roadway lighting levels and a known impact at higher lighting levels, there is a maximum lighting intensity that should be placed on roadway lighting levels.

PRESENTED POSTERS

Monday, September 18, 15:20-16:05

Session PS1
Presented Posters (D1/D3/D6/D8)
Monday, September 18, 15:20-16:05

PP9

VISUAL COLOUR-DIFFERENCE ASSESSMENT OF 3D PRINTED SAMPLES

He, R.[1], Xiao, K.[1], Pointer, M.[1], Melgosa, M.[2], Bressler. Y.[3]
[1] University of Leeds, Leeds, UNITED KINGDOM, [2] University of Granada, Granada, SPAIN,
[3] Stratasys Ltd., Rehovot, ISRAEL.
sdrh@leeds.ac.uk

Abstract

1. Motivation, specific objective

With the rapid development of colour 3D printing technologies, colour measurement and colour-difference evaluation of 3D printed objects require further studies to achieve faithful colour reproduction in 3D printing. Compared to 2D samples, 3D objects are more complex for the human visual system to process colour perception because of their uneven surface and non-uniform colour appearance. CIE TC 8-17 was established to develop methods for evaluating colour difference between 3D colour objects and investigating the effects on visual perception of colour difference caused by different 3D shapes, materials, and surface finish (matte/gloss). Considering that current colour-difference formulae were developed based on flat colour samples and have specific viewing conditions, it is unknown how these colour-difference formulae perform on 3D colour objects. Therefore, the aim of this study is to collect visual colour-difference data of 3D printed objects, investigate visual perception in lightness, chroma and hue scale, and test the performance of current colour-difference formulae on 3D objects.

2. Methods

Based on the five CIE recommended colour centres, red, green, yellow, blue and grey, the 3D samples with different magnitudes in each colour attributes (lightness, chroma, and hue) were printed using a Stratasys J750 colour 3D printer. A psychophysical experiment was conducted in a viewing cabinet fitted with a D65 simulator, and observers were asked to assess the colour-difference magnitude of each test pair of 3D samples using the Grey-Scale method which consists of nine grades of neutral patches. The grey-scale grades judged by observers were collected from the visual assessment and converted to the visual colour-difference data using the fitted relationship between the grey-scale grades and their corresponding CIELAB/CIEDE2000 colour differences. The correlation between the visual colour-difference data and the calculated colour-difference data were analysed and quantified by the metrics of R^2 value and *STRESS* (Standardized Residual Sum of Squares). Furthermore, the results achieved were compared to previous studies and the colour-difference data collected from 3D printed objects were reviewed.

3. Results

The visual colour-difference data have a linear relationship with those calculated using the colour-difference formulae, and the R^2 values for CIELAB and CIEDE2000 are 0.6244 and 0.6986, respectively. The STRESS value achieved using CIELAB was 28.6 units, and 25.9 for CIEDE2000. Regarding the 3D sample pairs respectively contributed by different attributes, the calculated colour differences in lightness scale are more corelated to the visual data, then is hue scale, and the least corelation between the calculated and visual colour differences occurs in chroma scale. It is indicated that chroma differences in colour-difference formulae was overestimated and the parametric factors need to be optimised to improve the accuracy of predicting colour difference of 3D colour samples.

4. Conclusions

In this study, a psychophysical experiment was conducted to collect visual colour-difference data of 3D printed objects to investigate colour perception in lightness, chroma and hue scale. The results shown that CIEDE2000 colour-difference formula has slightly better performance than CIELAB. When the three attributes were in the same magnitudes of colour difference, it

was easier for observers to assess lightness and hue differences of 3D objects but not chroma. The parametric factors related to lightness, chroma and hue differences in colour-difference formulae need to be optimised specifically for 3D objects.

PP11

IMPROVEMENTS TO CIECAM16 AND FUTURE DIRECTIONS

Hellwig, L[1,2], Stolitzka, D.[1], Fairchild, M.D.[2]
[1] Samsung Display America Lab, Samsung Electronics, San Jose, CA, USA,
[2] Munsell Color Science Laboratory, Rochester Institute of Technology, Rochester, NY, USA
luke.hellwig@samsung.com

Abstract

1. Motivation, specific objective

The approval of CIECAM16 by the CIE last year represents the third iteration of the CIE color appearance models, after CIECAM97s and CIECAM02. In this work, we analyze performance and logical consistency of the CIECAM16 formulas, focusing on the equations for brightness, lightness, colorfulness, and chroma. We discuss current research trends related to the structure of color appearance models and next objectives for color appearance standardization.

2. Methods

CIECAM16 evolved out of CIECAM02 and CIECAM97s, which itself was an amalgamation of several different color appearance models. By tracing the lineage and evolution of CIECAM16's formulas, we can assess whether the process of transcription and development from one model to the next has maintained the intent of the original formulas. Furthermore, systematic testing of the dependence of CIECAM16's predictions on quantities such as stimulus luminance and background luminance allow us to directly test whether the formulas remain perceptually valid and in agreement with their stated target behaviour. Additionally, performance on the LUTCHI color appearance dataset serves as an important metric for evaluating any proposed modifications to CIECAM16; theoretical improvements are only useful if they also maintain or improve current performance on the LUTCHI data.

3. Results

Our analysis reveals significant theoretical flaws in the formulas for CIECAM16. The adaptation of the Hunt model to CIECAM97s led to a nonlinear relationship between brightness and lightness, which in turn leads to a perceptual paradox in CIECAM16. Restoring the linear relationship between brightness and lightness fixes this theoretical shortcoming while improving performance on the LUTCHI data. Additionally, we find that multiple competing background dependencies can lead to unrealistic predictions of infinite colorfulness and brightness when the background is dark. Simplifying these dependencies brings the model back into line with the LUTCHI dataset.

4. Conclusions

Our proposed improvements to CIECAM16 increase the performance and theoretical grounding of the formulas. Furthermore, they allow for improved models of the contribution of colorfulness to brightness (the Helmholtz-Kohlrausch Effect). In addition to these improvements, we will also highlight several current areas of color appearance research where data has suggested more refinement of the CIE standard color appearance model may be necessary.

PP16

QUANTIFYING THE POTENTIAL IMPACT OF LIGHTING UNIFORMITY ON PLANT GROWTH IN HORTICULTURAL INSTALLATIONS

Bertin, K.[1], **Mucklejohn, S. A**.[2], Raynham, P.M.[3], Zissis, G.[1], Moutsi, A.[2], Preston, B. [2]
[1] LAPLACE UMR 5213 CNRS-INPT-UT3, Université de Toulouse, 118 route de Narbonne, 31062 Toulouse CEDEX 9, FRANCE, [2] Ceravision Limited, 28 Tanners Drive, Blakelands, MK14 5BN, UK, [3] UCL Institute for Environmental Design & Engineering, University College London, 14 Upper Woburn Place, London WC1 0NN, UK
Corresponding author: georges.zissis@laplace.univ-tlse.fr

Abstract

1. Motivation, specific objective

It is generally accepted that high uniformity is essential to the successful growth of plants in protected horticultural installations such as commercial greenhouses. However, there seems to be very few quantitative studies to determine the uniformities required and the impact of having uniformities beyond the preferred range.

As a first step to determine the impact of uniformity variations on the growth and development of plants under artificial lighting the authors have undertaken a study based on luminaires for ceramic metal halide (CMH) lamps and LED luminaires to estimate the through-life changes in uniformities.

The reduction in output from the luminaires with CMH lamps is dominated by the degradation of the source and lamp failures. For LED luminaires the combination of degradation of the LED chips constituting the arrays and the failure of the electronic drivers will determine the reduction in output of the installation.

While CMH lamps are expected to have an economic life <10,000 h, LED luminaires are employed with the anticipation of economic life >50,000 h.

2. Methods

Using initial luminous fluxes and lumen maintenance factors (LMFs) measured for CMH lamps, the reduction in the average illuminance for an installation can be calculated. However, it is the variations in the LMFs that will determine changes in uniformity as a function of operating time. The authors have simulated these changes by generating LMFs and variations at intervals between 1,000 and 10,000 h. These values have been used to predict the range of changes to the uniformity over the same operating period.

Based on values from several lumen maintenance studies of LED chips using the IES LM-80 and TM-21 standards, the rates of degradation have been estimated as a function of time to 50,000 h. LM-80 requires measurements to at least 6,000 h.

TM-21 calculations for estimating the useful life of LEDs at a specified temperature are based on computing the normalized average lumen maintenance over a specified measurement time and fitting an exponential curve to the data. This fit is extrapolated to estimate a time to a specified average lumen maintenance. Typically this is LMF of 70% and is quoted as the L70 parameter. An alternative approach is to fit an exponential curve to the normalized data for each individual chip in the LM-80 report. The average lumen maintenance computed in this way agrees with the specified methodology to <1%, but has the advantage of estimating the light output variability at times beyond the measurement points. Calculation shows that the lumen variability remains essentially constant over the useful life of the chips. The guiding principle is that the extrapolation is valid only for 6 times the length of the measurements.

Failure rates for LED drivers have been estimated on the assumption they are dominated by the operating temperature. The predicted failure rates and variations have been made using an exponential distribution.

Using the initial lumen outputs and the LMFs estimates of the impacts on uniformity can be calculated. These values are independent of the failures of the drivers.

Similarly, an estimation of the reduction in output of an installation due to driver failures can be made independent of the changes in the LED chips. Combinations of these two mechanisms provides a guide to the decline in output for the entire installation as a function of operating time and temperature.

The driver temperatures in a set of LED luminaires within a commercial greenhouse lighting installation has been recorded over an extended period. These values have been used as the basis for the prediction of the long term uniformity of the installation.

The analyses outlined above have not included the impact of the accumulation of dirt on the transparent parts of the luminaires.

3. Results

For an installation designed for uniformity 0.70 in a greenhouse measuring 81 x 50 m, mounting height 2 m, with luminaires suitable for 315 W CMH lamps, our calculations show that while the relative illuminance drops from 6,188 lx initially to 4,410 lx at 10,000 h, the uniformity will vary between 0.75-0.65. This apparently incongruous result, whereby the uniformity might improve with time, is due to the LMF variation and the random distribution of luminaires within the installation. These calculations do not include any lamp or ballast failures, these will be addressed in the next modelling phase.

LED luminaires have a major advantage over conventional light sources in that many individual chips are required for the arrays in the luminaire. The variability in light output between luminaires is reduced by the square root of the number of chips in the arrays compared with conventional light sources. This reduction can be highly significant. Many LED luminaires use 0.5 or 1.0 W chips. For luminaires rated between 150 and 250 W this translates to 150-500 chips. These numbers result in a reduction in variation of light output between luminaires by factors of 12.7 to 22.4.

The next models will include 10% LED driver failures at 50,000 h if there are operating within their design temperature range.

4. Conclusions

Like all light sources LEDs display variations in all measured parameters. A typical percentage coefficient of variation (standard deviation/average x100) of light output lies in the range 2.5 to 3.5%. Typically this leads to a 10% variation in output between chips. This number is comparable to that obtained for conventional light sources such as CMH lamps. With the lives of LED lamps extending far beyond the 6,000 to 10,000 h reported LM-80 reports, it is important to understand if the variability in LED chip output for lives beyond this time remains stable.

The calculated variation in installation uniformity is approximately 0.5 to 1.0 of the 2σ variability in light source output. This expected variability does not change significantly over life for the CMH lamps.

PP23

EVALUATION OF ARTIFICIAL LIGHT AT NIGHT IN URBAN COMMERCIAL AREAS BASED ON COLOR HARMONY AND VISUAL ENTROPY

Chen, S.F.[1], Zeng, X.X.[1], Zhang, B.[1], Lin, Y.[1], Yao, Q.[2]
[1] University of Tongji, Shanghai, CHINA, [2] University of Fudan, Shanghai, CHINA,
linyi_tjcaup@tongji.edu.cn

Abstract

1. Motivation, specific objective

In the 20th century, the implementation of lighting technologies has served various purposes such as enhancing safety and security, showcasing historical and architectural significance, and boosting the economy and tourism at night. While artificial light at night (ALAN) has increased the color variety of the urban night, it has also altered the spectral composition of the night sky, which can disrupt natural ecosystem rhythms. Additionally, the subjective aesthetic judgment of designers and the influence of owner preferences make it difficult to effectively control the artistic level and aesthetic value of the urban ALNA.

Color harmony is an important concept in visual aesthetics, referring to the pleasing combination of colors in adjacent areas. Many theories and evaluation models have been developed to quantify the level of color harmony in image aesthetics, yet these have not been applied to evaluate urban ALNA. To address this gap, we propose applying color harmony theory to evaluate multicolor lighting scenes in urban areas. We also introduce entropy, a measure of the inherent degree of chaos in a system, to describe the richness of urban ALNA based on human visual perception. To operationalize this, we developed a visual entropy model and collected hyperspectral imaging (HSI) data from 18 commercial districts in Shanghai, China, to analyze and evaluate the color harmony and richness of night scene lighting. We further validated the results using psychophysical experiments and proposed a quantitative evaluation method based on objective data.

2. Methods

Hyperspectral Data Acquisition Method: HSI data for 18 urban night scenes at six locations in Shanghai, including the North Bund, the Baiyulan Square, Lujiazui, the Bund, Nanjing East Road, and Xingye center, was collected using a TOPCON SR5000-HS 2D Spectroradiometer. The instrument was positioned at a height of 1.5 meters on the sidewalk to capture the HSI data for each scene. The data resolution was 688×512 pixels, and the scanning wavelength range was 380~780 nm (5 nm interval), resulting in 81 spectral layers with 688×512 pixels per layer. In total, 6,340,608 spectra were obtained for the 18 scenes.

Color Harmony Analysis Method: The spectral of each pixel in each scene was converted to the CIE 1976 L*a*b* color space, and the main color tone in each scene was extracted using the Mean Shift algorithm. The color harmony value between the main color tones in the scene was calculated using Ou & Luo's bichromatic harmony model. The weights between different color pairs and harmony values were obtained using Solli et al.'s image analysis method, resulting in the overall color harmony value of the entire scene.

Visual Entropy Analysis Method: The pixels of each scene was divided into 22,016 "cells" by a 4x4 grid, and the CIE 1976 L*a*b* values of each cell were defined as the average of the 16 pixels in the grid. Comparing the color difference (ΔE^*_{ab}) between each cell and the remaining cells, the cells with a color difference of less than 2 were labeled with the same number, while cells with a color difference of greater than 2 were labeled with different numbers. The number (i) of each cell and the average value (j) of the adjacent cell number were obtained, and the proportion of cells with the same (i, j) in the entire scene was

calculated. Finally, the visual entropy model of the scene was constructed based on Shannon entropy theory to calculate the visual entropy value.

Psychophysical Experiment Method: The RGB images derived from the 18 scenes were displayed on a laboratory monitor and presented to the participants. They were asked to evaluate the color harmony and richness of each scene using a 7-point scale, ranging from "disharmonious" to "harmonious," and from “disrichness” to “richness” corresponding to scores of 0 to 6.

3. Results

The collected data from the 18 scenes indicated that the color harmony of the lit area is lower than that of the unlit area. Furthermore, the color harmony were found to have a negative correlation with the average brightness and saturation, with correlation coefficients of -0.132 and -0.197, respectively. In contrast, the visual entropy of the scenes had a positive correlation with the average brightness and saturation. In the case of urban at night, the background is typically black, and the luminance of the nighttime space is determined by the average brightness of the color. Therefore, the color harmony of the scene is negatively correlated with the average luminance of the scene, with correlation coefficients of 0.866 and 0.303, respectively. The visual entropy of the scene is higher with a higher average luminnace as it allows for more light to be received by the human eye, thereby enhancing the recognition of details. Additionally, the greater the difference in color purity of the scene, resulting from higher saturation, the lower the color harmony, but the higher the amount of information. Thus, the visual entropy of the scene is positively correlated with the saturation of the scene. Notably, the computer analysis results were highly consistent with the findings of psychophysical experiments.

4. Conclusions

This paper proposes a quantitative evaluation method for urban ALAN applications based on color harmony theory and visual entropy. The aim is to evaluate the aesthetic quality of urban night lighting using color harmony, and to assess the color information perceived by the human eye through a visual entropy model, providing a color perspective on the richness of urban ALNA. Utilizing complementary colors, similar saturation, and similar lightness can effectively enhance color harmony and decrease visual entropy, thereby improving the comfort of urban nighttime space.

Traditional quality evaluation of urban ALAN is based on subjective preference evaluation, focused on one or several lighting factors. However, with advances in computer science, neuroscience, biosensing, and the introduction of computer vision, deep learning, and physiological feedback technologies, the shift towards objective quantitative evaluation of ALNA aesthetics is becoming a new trend in the field of urban lighting research.

PP3

DEGRADATION OF BIOLOGICAL POTENCY IN LED LIGHT SOURCES WITH THEIR LIFETIME

Belgers, S.[1], Schlangen, L.J.M.[1], Cuijpers, R.H.[1], Heynderickx, I.[1]
[1] Human-Technology Interaction Group and Intelligent Lighting Institute, Department of Industrial Engineering and Innovation Sciences, Eindhoven University of Technology, Eindhoven, The NETHERLANDS
s.belgers@tue.nl

Abstract

1. Motivation, specific objective

Light affects us in many more ways than just visual perception. It modulates our sleep, our mood, and our circadian rhythm – effects we summarize as biological potency. This biological potency depends on the spectral power distribution of the light: our biological system is most affected by light with increased low-wavelength (blue) content. Previous research has already described the importance of incorporating this biological potency into lighting solutions. There are clear recommendations for the amount of biological potency light should have, how to incorporate it in the design process of lighting solutions, and what metrics are suitable proxies for the biological potency.

As LED light sources age, their lumen output degrades, and their colourpoint changes. Currently, the lifetime of LED light sources is most often determined based on the lumen maintenance, sometimes in combination with the shift in colourpoint. Lumen maintenance is the remaining percentage of lumen output with time, and the resulting lifetime is determined as the time in burning hours until the lumen maintenance is below a specified amount, often 80% (L_{80} standard). Furthermore, the shift in colourpoint of the LED source with age is measured in absolute distance to the initial colourpoint in the CIE 1976 (u'v') colour space. Clearly, both lifetime specifications are solely based on visual perception metrics, and are not suitable as proxies for the biological potency of the light. Hence, the design and implementation of light solutions with suitable biological potency require different metrics that reflect how the biological potency degrades during aging of the LEDs.

The colourpoint is anyway not a good descriptor of biological potency, as light with the same colourpoint can have different biological potency (i.e., through a different contribution of the spectral distribution in the low-wavelength region). The standardly used metrics of biological potency are based on (melanopsin) photoreceptor excitation. Two related metrics are: (1) the melanopic daylight efficacy ratio (mel-DER), and (2) the melanopic equivalent daylight illuminance (mel-EDI). Mel-DER is the ratio of melanopic luminous efficacy between standard (D65) daylight and the test light, and can be considered to be a metric of the biological potency normalised per unit of light. Mel-EDI quantifies the biological potency of light by indicating the amount of standard D65 daylight required to obtain light with equal melanopsin photoreceptor excitation as the test light. Thus, it would be more logical to use these metrics to quantify the lifetime of LED lighting solutions for their biological potency.

This study compares how the current LED lifetime metrics relate to lifetime in terms of biological potency.

2. Methods

For this study, data on the spectral power distribution over time was provided for ten batches consisting of 16 LEDs subjected to an accelerated aging process through increased operating temperature and increased operating current. Each batch consisted of a unique combination of type of LED, operating current, and operating temperature, but with a different aging time for the different LEDs with a maximum of 8000 burning hours.

Only four of the measured batches were included in this study as other batches had either not been sufficiently aged for the planned analysis or did not consist of white LEDs. Within each batch, only LEDs that had more than three datapoints over the full lifetime based on the L_{80} standard were included; in practice this implied that 50.5% of the data were used. Each LED had between three and fourteen datapoints. We used linear interpolation to obtain datapoints for every hour and to be able to average across LEDs. The end-of-life was used to normalise time to a scale from 0 to 100%, where 100% corresponded to a lumen maintenance of 80% of the original light output.

For each batch, the average mel-DER before aging was compared to the average mel-DER at the end-of-life, and the average lumen maintenance at end-of-life (i.e., 80%) was compared to the average mel-EDI maintenance at the end-of-life.

The lifetime of the LEDs is furthermore also determined based on 80% maintenance of the biological potency determined through the melanopic EDI. This lifetime is compared with the L_{80} lifetime, in order to provide insight in the differences in lumen-based lifetime and biological potency-based lifetime.

3. Results

The average mel-EDI maintenance is significantly lower than the lumen maintenance at the lumen-based end-of-life for all four batches. Furthermore, the mel-DER was significantly higher before aging than at the lumen-based end-of-life for all four batches.

The mel-EDI maintenance drops below 80% on average 25% quicker than the lumen maintenance for the batch where the aging was most aggressive. For the other batches, the mel-EDI drops below 80% on average 10% quicker.

We also looked at the shifts of the colourpoints during ageing, but they stayed well within the norm.

4. Conclusions

Currently, there is little information available about how aging of LEDs affects their biological potency. It is well known that the lumen output degrades over time, and it is thus no surprise that the biological potency degrades as well. While colour shift guidelines exist, and shifts towards or away from the blue area are associated with a changed biological potency, this is no suitable proxy for biological potency nor does it provide insight in the combined effect of reduced lumen output in combination with colour shift.

Data on accelerated aged LED sources show that biological potency per unit light output changes throughout the LED lifetime. The biological potency degrades quicker than the lumen degradation. As such, lumens are not a suitable proxy for the degradation in biological potency. Our results show that LEDs need to be replaced earlier when biological potency is to be maintained during its lifetime. The current data suggest that this should happen between 10% to 25% earlier, depending on the operating conditions.

PP6

DOES LIGHT AFFECT FUNGAL GROWTH? EXPERIMENTAL ANALYSIS UNDER MONOCHROMATIC LED SOURCES

Bellia, L.[1], Birolo, L.[2], Corsaro, M. M.[2], **Fragliasso, F.**[1]**,** Genovese, A.[3], Palella, B. I.[1], Petraretti, M.[3], Riccio, G.[1], Stanzione, I.[2]
[1] Department of Industrial Engineering, University of Naples Federico II, Naples, ITALY, [2] Department of Chemical Sciences, University of Naples Federico II, Naples, ITALY, [3] Department of Biology, University of Naples Federico II, Naples, ITALY
francesca.fragliasso@unina.it

Abstract

1. Motivation, specific objective

Light plays a fundamental role in museum applications. The choice of the proper source is fundamental in improving visitors' perceptive experience and can represent a useful mean to enhance cultural heritage fruition. However, the exposition to radiation can trigger physical, chemical, or biological degradation phenomena, altering the characteristics of the exhibited objects. Furthermore, light-induced damages can be made worse when specific temperature and humidity conditions occur.

Photochemical effects depend both on the spectral power distribution (SPD) of the installed light source and on the spectral sensitivity of lit objects. Ideally, given a specific material, to reduce the damages due to radiation exposure, designers should select light sources characterized by low energy content in the wavelengths for which the sensitivity of the material is high. Nowadays, as previous research testifies, thanks to the introduction of multichannel LEDs this idea is not impossible to put in practice. Indeed, some researchers studied the photosensitivity of specific materials (for example pigments in paintings) and then designed ad-hoc spectra characterized at the same time by high colour rendering index (to enhance artworks' perception) and reduced energy content for risk wavelengths (to protect exposed objects).

Biological risk is more complicated to analyse. The growth of different species of microorganism depends on both the exhibited objects (representing the growing substrate) and the environmental characteristics in exhibit spaces (interaction among light, humidity and temperature). Among microorganism, fungi can be very harmful, since they are able to attack other organic materials and can release in the surrounding pigments furtherly damaging the artifacts.

The difficulty in facing biological risk comes to light even from an analysis of the specific regulations. For example, regarding the photochemical risk, CEN/TS 16163: 2014 prescribes different limit values for illuminance and total yearly luminous exposure on exhibited objects, depending on their sensitivity and classifies materials according to their nature in four categories (no sensitivity, low sensitivity, medium sensitivity, and high sensitivity). On the contrary, as concerns the biological risk, it underlines that specific combinations of light, temperature and humidity can facilitate the growth of some micro-organisms, but only suggests that biological problems should be addressed by a team of specialists.

In this case, assessing spectral sensitivity to light exposure could be a promising tool. It could reveal if radiation rich in specific wavelengths is able to stimulate or slow down the microorganisms' growth process. Then, this information could be used for the design of specific SPDs.

The goal of the paper is to investigate the growth rate of five fungal strains isolated from a Zoologic Museum and cultivated inside ad-hoc built experimental boxes equipped with four different monochromatic LED sources. The acquired information is useful for a future design of ad-hoc SPDs to be implemented in museum applications.

2. Methods

Five fungal strains were collected from a Zoological Museum during a sampling campaign that took place in February 2021. They are *Aspergillus fumigatus* (057f), *Bjerkandeira adusta* (058f), *Fusarium oxysporum* (059f), *Penicillium chrysogenum* (060f), and *Penicillium granulatum* (061f). For each selected fungal strain, a triplicate of PDA petri dishes was inoculated with a small starting inoculum of spore suspensions. Then they were incubated in four ad-hoc built boxes (40 cm wide, 100 cm long and 40 cm high) completely closed to exclude external light and lit inside by eight monochromatic chip LEDs. Triplicates of each PDA petri dishes were observed weekly for photographical documentation under a laminar flow hood. To evaluate the fungal growth in each recovered digitized photograph, the latter were analyzed using Trainable Weka Segmentation, a plugin of the open-source digital image analysis software Fiji. In each box LEDs were characterised by different peak wavelengths, i.e., 460 nm (blue light), 518 nm (green light), 594 nm (yellow light), and 638 nm (red light). Lighting system was set to irradiate uniformly all the dishes (30 for each box), i.e., to obtain at the floor level of the boxes the same irradiance value irrespective of the used source (about 0.72 W/m^2) and a high uniformity value (about 0.94). To do that, irradiance measurements were performed on a rectangular grid composed of 21 points.

During all the experiment (28 days) humidity and temperature were constantly monitored to account for the interactions between different environmental parameters.

Proteins and carbohydrates were extracted from samples recovered from each fungal plates. Protein profiles were analysed by electrophoresis under denaturing conditions, whereas total carbohydrates were obtained by phenol assay.

3. Results

The exposure to monochromatic radiation showed different behaviours in the growth of tested fungal strains. The exposure conditions at 594 nm and 638 nm had a stimulating effect especially on *B. adusta*, *P. granulatum* and *F. oxisporum*, while the 518 nm radiation improved the growth of *A. fumigatus and P. chrysogenum.* Overall, all fungal strains grew less, when exposed to 460 nm. Protein profiles were visibly affected by the wavelength fungi were exposed to. As for carbohydrates, the detected amount was influenced as well.

4. Conclusions

Photomicrography-based image analyses turned out to be a useful tool to estimate the fungal growth at different illumination conditions. The collected data represent a first step for further studies to assess which type of lighting is most suitable in the museum environment to better preserve museal objects from fungal contamination and degradation.

PP18

SPARKLE AND GRAININESS INDEX MEASUREMENT OF METALLIC COATINGS WITH MATTING AGENT

Osumi, M.
Office Color Science Co., Ltd., JAPAN
masayuki-osumi@nifty.com

Abstract

1. Motivation, specific objective

In the recent years, automotive exterior coatings contain many types of metallic and pearl pigments, which are multi-layered. Metallic coatings have different brilliance and sparkle colours and textures depending on the illumination and viewing angle. On the other hand, the texture variation of automotive exterior coatings tends to diversify, and one of example is matte coat, and in the recent years, this type of coating has been rapidly increasing. For this reason, there are concerns about whether a device that measures indicators related to sparkle and graininess can measure without problems. Therefore, in this study, we prepared a metallic coated panel with a matte coat, and observed the microstructure of its surface with a digital optical microscope or a laser confocal microscope, spectroscopic imaging, portable gonio-spectrophotometer, surface analyser, and evaluated and analysed its optical behaviour using illumination under various optical geometric conditions. As for the optical geometric conditions, three linear directional illuminations of three different angles generated by light guides were used for sparkle measurement, and three types of integrating sphere illumination with SCI / SCE / 0-degree light detection were used for graininess measurement. After measurement, CIELAB colour values, spatial distribution in the CIELAB colour space, sparkle and graininess index were calculated.

2. Methods

Digital optical microscopes (KEYENCE VHX-7000) and laser confocal microscopes (KEYENCE VX-1000) were used to measure the structure and fine 3D shape of coated panel surfaces. The former has a full-focus function with focus stacking, and can measure three-dimensional shapes at the same time. The latter can also be used in conjunction with laser light scanning to accurately analyse the 3D structure and shape of a surface. Spectroscopic imaging consisted of a CCD imaging device with Peltier cooling and anti-blooming mechanisms, liquid crystal tuneable filters (LCTFs), and white LED illumination that combined UV-excited light with R, G, and B phosphors to achieve even energy distribution over the entire wavelength range of visible light. In directional lighting for sparkle measurement, a light guide with a linear output end is used, and the illumination angle is 15 degrees, 45 degrees, and 75 degrees from the normal direction of the coating panel to be measured, and the light is received in the vertical direction. For diffuse illumination for the purpose of measuring the graininess, three different integrating spheres with diameters of 20 cm, SCI/SCE/0, were applied. CCD devices capture images via LCTF at a resolution of 380 dpi and 772 x 580 pixels every 10 nm between 420 and 700 nm. Before measurement, a lattice pattern consisting of white and black lines was applied to compensate for registration errors caused by LCTF optical aberration in each wavelength image. To obtain highly accurate spectral reflectance and imaging information, each wavelength image was corrected for x and y shifts by a measurement lattice pattern. The test panels were made with aluminium flakes and matting agents, and each panel was coated on a white and black substrate by spray application. In addition, we compared the Sparkle and Graininess Index measurement trends of portable gonio-spectrophotometers (BYK Gardner, BYK mac I), which are widely used to measure the exterior coatings of commercially available automobiles. A surface analyser (Canon RA532H) was used to measure gloss values, and measure 3D reflection profiles of reflections of near specular area at 20 and 60 degrees.

3. Results

The coating panels used for the observation were prepared with only a matting agent in the coating film, painted using only a certain concentration of aluminium flake in the coating film, and a combination of both a matting agent and a certain concentration of aluminium flake in the coating film. As a result of using a digital optical microscope and a laser confocal microscope, it was possible to accurately observe the three-dimensional surface structure with fine undulations of the matting agent and the shape of the distribution in the coating film of the aluminium flake, and obtained high-precision shape data. In addition, we measured the Graininess Index by diffused illumination due to changes in the presence or absence of aluminium flake and the concentration in the coating film of the matting agent, and clarified the influence of the measured values on the scattering effect of the matting agent. Furthermore, using a surface analyser, we clarified the relationship between the gloss values of 20 and 60 degrees and the scattering effect of the matting agent on coated panels containing aluminium flake based on changes in the reflection profile in the vicinity of specular reflection. Similarly, in the measurement of gonio-spectroscopic imaging, we acquired spectroscopic images for each measurement angle due to changes in the concentration of the matting agent and captured the changes. The change in 75 degrees illumination was particularly characteristic, even at low concentrations of the matting agent. For the illumination of the integrating sphere for grain size measurement, the L* distribution was calculated for the centre 400 × 400 pixel range of the image. The measurement results of SCE and 0 degree light detection show high contrast, although dark spots occur near the centre. On the other hand, SCI measurement images have excellent uniformity, but are strongly affected by surface scattering. Numerical compatibility with the BYK mac i was not high in the case of SCI.

4. Conclusions

Sparkle and graininess measurement problems of metallic coated panel with matte coating were verified.

The three-dimensional microstructure was measured using a digital optical microscope and a laser confocal microscope for surface observation.

Using a portable gonio-spectrophotometer capable of measuring Sparkle and Graininess Index and a surface analyser, we measured coated panels combining aluminium flake and matting agents, and clarified the relationship between the light diffusion effect of the matting agent.

Spectroscopic imaging measurements were performed with 3-angle directional illumination. Among them, the diffusion effect of illumination light at 75 degrees illumination was characteristic.

Spectroscopic imaging measurements were performed with three types of integrating sphere illumination. Among them, SCI was significantly affected by matting agents.

Session PS2
Presented Posters (D3/D1/D6)

Monday, September 18, 15:20-16:05

PP2

METHOD FOR EVALUATING FIDELITY OF RESTITUTION OF SUBJECTIVE IMPRESSIONS IN IMMERSIVE VIRTUAL REALITY IN DAYLIT INTERIOR SCENES

Atié, M.[1], Drozd, C.[1], Siret, D.[1], Vigier,T. [2]
[1] Nantes Université, ENSA Nantes, Ecole Centrale Nantes, CNRS, AAU-CRENAU, UMR 1563, Nantes, France, [2] Nantes Université, ENSA Nantes, Ecole Centrale Nantes, CNRS, LS2N, UMR 6004, Nantes, FRANCE
michele.atie@crenau.archi.fr, toinon.vigier@univ-nantes.fr

Abstract

1. Motivation, specific objective

Virtual Reality (VR) and hyper-realistic imaging technologies can enhance user experience and offer faithful immersive representations for various fields, such as architectural lighting education. Projecting 360° stereoscopic High Dynamic Range (HDR) photographs of daylit places in VR may offer a new way of learning and experiencing subjective impressions and allow architectural students to explore the images in a more interactive and hands-on way compared to traditional tools.

However, this technology might not be able to offer the realistic qualitative experience of luminous atmospheres lived in real indoor scenes. Head Mounted Displays (HMD) cannot reproduce HDR images. Headset screens only support Standard Dynamic Range (SDR), resulting in image compression. Therefore, the HMD might not be able to offer a promising medium to study subjective impressions of luminous atmospheres in architectural education.

Numerous studies have simulated immersive virtual environments as a surrogate environment to the real world for the study of subjective impressions of light such as pleasantness, visual comfort, evenness or glare. However, to our knowledge, few works introduce the study of the qualitative experience of luminous atmospheres by rating real daylit indoors and the 360° stereoscopic HDR photographs of these indoors projected in HMD.

Thus, this study aims to investigate how VR technology can be used as a surrogate for real environments in addressing subjective impressions in daylit interior scenes. Findings from this experiment tend to reveal if VR HMDs can be a reasonable surrogate for real-world lighting environments when evaluating luminous atmospheres. The adequacy of this technology in replicating real-world qualitative experiences can enhance the learning experience.

This work studies the adequacy of projecting 360° stereoscopic High Dynamic Range photographs in VR by evaluating participants' qualitative experience in real scenes and comparing it with the virtual environment. In this study, we conduct subjective assessments of daylit indoors in several remarkable buildings built by famous architects such as Le Corbusier, Jean-Nouvel, and Tadao Ando and ordinary buildings such as offices, meeting rooms and classrooms.

This presentation introduces a novel method for comparing subjective impressions of luminous atmospheres in real daylit indoors and photographs of these indoors captured using a 360° professional camera displayed on an HMD.

2. Methods

This section introduces the method and conduction of the experimental study ranging from evaluating of the real places to creating the immersive environment of the captured scenes.

In the first part of our method, we present our experimental design in real environments.

This step presents the selection of scene conditions, the method used for the physical characterization of the daylit indoors by conducting illuminance measurements on a regular grid on the floor level; the method used to capture 360° HDR stereoscopic photographs and the method of the conduction of qualitative and quantitative evaluation of these scenes by providing questionnaires to different groups of participants in each different place. Contrary to previous studies that evaluated a few aspects of daylight dimensions, we present our questionnaire based on selecting expressions in articles evoked by experts and architects. The questionnaire evaluates first impressions and five dimensions related to the qualitative experience of the place, such as light, space, incarnation and references. In the second part of the questionnaire, we evaluate the quantitative measurements of daylight, such as brightness, visual comfort and contrast.

Lastly, we present the collected data of the physical and subjective evaluation of the luminous atmosphere of real architectural places.

In the second part of our method, we present our experimental design in virtual environments.

This step consists of the content acquisition, the post-processing workflow, the design of the virtual environment in HMD and the evaluation protocol. In addition, we provide display specifications and tone-mapping operators (TMOs) techniques used to represent accurate HDR images in the display. We present the method of developing the user interface in VR to evaluate our 360° stereoscopic HDR photographs.

In this second part of our method, we intend to collect data on evaluating the 360° HDR stereoscopic photographs projected in HMD by providing a similar questionnaire used in real scenes with a different group of participants. This part will be completed in future work.

3. Results

The study is conducted in France over several days in iconic and ordinary daylit indoors. Participants are asked to rate the different dimensions of subjective impressions by viewing the real scenes. We provide qualitative and quantitative subjective evaluations from participants and an analysis of the luminous atmospheres of the different places. In addition, we provide information about illuminance measurements, daylight factor and physical characterisation of the different scenes. This information helps architects assess interior buildings lighting levels and provides insights for architectural students during conceptual design.

4. Conclusions

We present a novel method for assessing and comparing subjective impressions in real interior daylit places via immersive 360° HDR stereoscopic photographs of these places displayed in HMD. We provide preliminary results of applying the first part of our method on iconic and ordinary buildings. In future work, we intend to compare the first results to one of the photographs projected in HMD. This work is an important step toward improving education and perception of daylight in architectural studies. Following the final findings, the presented experimental method allows us to identify the effectiveness of VR technology in replicating real-world lighting subjective impressions for architectural education.

PP4

THE IMPACT OF COLOUR AND SIMULATION DETAIL ON SUBJECTIVE IMPRESSIONS OF DAYLIT SCENES SHOWN IN VIRTUAL REALITY

Omidfar-Sawyer, A.[1] and **Chamilothori, K.[2]**
[1] University of Michigan, Ann Arbor, USA, [2] Laboratory of Integrated Performance in Design, Ecole polytechnique fédérale de Lausanne, Lausanne, SWITZERLAND

aomidfar@post.harvard.edu
k.chamilothori@tue.nl

Abstract

1. Motivation, specific objective

Renderings, or simulated visualisations of a 3D environment, have been widely used in studies investigating the effect of lighting on human perception and experience. The outcomes of these rendering-based studies are affected by a series of user choices in the simulation process, such as the rendering settings, as well as decisions related to the scene content, such as the level of detail of the scene, the choice of materials and textures, and the modelling of the surrounding environment. Although considerable research has been devoted to investigating the impact of parameters such as the choice of materials and the level of detail on simulation accuracy or the participant's sense of presence, we have a limited understanding of how these parameters affect the visual impressions of the depicted scene. This gap in knowledge is particularly important considering the growing use of rendered scenes and virtual reality (VR) head-mounted displays in experimental studies that investigate the user experience of lit environments. Recent studies in lighting research using rendered scenes differ in their methodological choices regarding both the level of detail and the presence of colour in the scene, ranging from achromatic scenes with no furniture to mainly achromatic scenes with furniture or scenes with coloured textures and furniture. Existing studies in real environments show that both colour and level of detail are important: the presence of coloured surfaces or objects has been shown to render a space more attractive, stimulating, and bright, while the presence of furniture has been shown to influence the perceived spaciousness of a room. As the use of VR for research in human factors and in lighting is growing in popularity, it is essential to examine the effect of such simulation choices on participants' visual impressions and to provide a reference for future studies. To this end, this work investigates the effect of coloured materials and the presence of furniture on participant impressions through an experimental study in immersive VR.

2. Methods

This study employed renderings of a daylit typical office space with a large south-facing window under clear sky conditions. The experiment followed a fractional factorial experimental design with three factors: *presence of furniture* (two levels: presence and absence of office furniture and equipment, plants, and decoration), *scene colour* (three levels: grayscale, partly coloured with only the view through the window and the plants being coloured, and fully coloured, including wooden flooring), and *window treatment* (six levels of shading system variations with a 40% opening ratio, chosen based on existing research on the effect of shading system designs on occupant experience). To reduce the number of factor combinations, the *scene colour* level 'partly coloured' was not combined with the *presence of furniture* level 'no furniture'. The 30 resulting scene variations were modelled in Rhinoceros 5 and rendered in Radiance using DIVA-for-Rhino following an existing workflow to generate 360° omnidirectional stereoscopic projections of the scenes. The material properties and detailed rendering settings are omitted from this abstract for brevity. The resulting HDR renderings were tone-mapped to a low dynamic range using the Reinhard02 tone-mapping operator and transformed to TIFF files. The scenes were presented to participants using the standalone VR headset Oculus Go, which provides a resolution of 2560x1440 pixels and a maximum refresh rate of 72 Hz.

A total of 100 participants (63 women, 37 men) took part in the study. Participants were unpaid volunteers over 18 years of age, recruited by email or in person. Each experimental session lasted a maximum of 20 minutes. Each participant saw all six levels of *window treatment* in random order, in a random combination of the factors *presence of furniture* and *scene colour.* After experiencing each scene, participants were asked to verbally rate their subjective impressions of the office space (such as how pleasant, interesting, exciting, calming, and complex they rated the space) using a 11-point rating scale from 0 (not at all) to 10 (highly).

3. Results

Linear mixed model (LMM) analyses were conducted to account for the use of repeated measures. In each LMM, the corresponding subjective responses were specified as the dependent variable, the *presence of furniture*, *scene colour,* and the interactions between *presence of furniture* and *scene colour* were specified as fixed effects, and the participant number was specified as a random intercept. *Window treatment* was also added as a covariate and was significant for all attributes, but is not reported further as it is outside the scope of this paper. No significant interactions were found between *presence of furniture* and *scene colour* for any of the studied variables, and thus the interaction terms were removed from the LMM.

The presence of furniture in the scene significantly influenced all studied attributes. The higher level of detail was shown to lead to more positive evaluations for all attributes, with an increase of up to 17.9% and 21.5% in the 11-point scale regarding how interesting and complex the space was perceived, respectively. Similarly, the presence of colour in a virtual scene significantly influenced how pleasant, interesting, exciting, calming, and complex the scene was perceived. Grayscale scenes significantly lowered the evaluations for all attributes compared to coloured scenes, with the largest decrease being 11.1%, regarding how pleasant the space was rated. Grayscale scenes were also rated 7.3% and 8.9% lower in pleasantness and calmness, respectively, compared to partly coloured scenes. Lastly, coloured scenes led to an increase of 5% in how exciting and complex the space was rated compared to partly coloured scenes.

4. Conclusions

This experimental study examined the impact of colour and furniture on participants' subjective impressions of a daylit typical office shown in immersive VR. The findings show –to our knowledge, for the first time— that these choices in the simulation process can significantly influence participant responses (with a change as large as 21.5% found in the current study) and should be considered carefully in the design of experimental studies with simulated visual stimuli.

PP15

MIXED EFFECT OF TIME OF DAY AND CORRELATED COLOUR TEMPERATURE ON DISCOMFORT GLARE

Maskarenj, M. [1], Altomonte, S.[2]
[1,2] Université catholique de Louvain, Louvain la Neuve, BELGIUM
maskarenj.marshal@uclouvain.be

Abstract

1. Motivation, specific objective

Daylight supports multiple visual and non-visual human needs, sustaining environmental perception, safety, circadian entrainment, as well as various physiological and psychological processes. Modern work practices have led occupants to spend significant portions of their day indoors, increasing reliance on electric lighting for their visual needs. Even for buildings with external views, blinds tend to be closed at first instances of glare, and are often not reopened afterwards. Lack of natural light exposure can lead to circadian disruption, and other adverse effects. Additionally, the use of electric light during daylit hours has energy implications. Towards maximising the benefits offered by daylight, glare responses need to be better characterised. Yet, although models for glare prediction exist, they do not address the within- and between-subject variances that may arise from personal and contextual factors. These variances need to be better framed towards enhancing glare tolerance.

Previous studies have established that source spectrum influences glare perception, with higher estimates of discomfort glare evoked by shorter wavelengths. Time of day (ToD) has also been found to influence glare evaluation, with increasing tolerance reported as the day progresses. Yet, no research has been done on the potential mixed effects of spectrum and time of day on glare assessments. A more thorough understanding of these phenomena is relevant since lower tolerance to glare, for light of given correlated colour temperature (CCT), at early hours could cause occupants to close blinds in the morning, switching to electric lighting and depriving them of the benefits offered by daylight, often, for the rest of their day. In response, this study has been devised to study the mixed effect of time of day and source spectrum on glare perception.

2. Methods

To more robustly detect the mixed effect of ToD and CCT on glare perception, a laboratory experiment has been designed in a room without access to daylight. A category-rating approach has been deemed more suitable, using LED luminaires that are tunable in both intensity and CCT. A semi-hexagonal chamber has been constructed, with the subject sitting in front of a glare source that can be set to photometric and physical values corresponding to four IES-GI thresholds. The experimental variables include, across each of the four glare thresholds, three ToDs and two CCTs, whose order of presentation is randomised for each participant and counterbalanced for each experimental session. For studying variations across ToD, the experiment is repeated by each subject on three days, either in the Morning (09:00), at Midday (13:00), and in the Afternoon (17:00). At each session, the sequence of IES-GI glare stimuli is repeated with the light source and the background luminance set at a CCT of, respectively, 2000K (warm) and 6500K (cold). A sample size of 36 participants has been calculated as having a sufficient power, being capable to estimate effect sizes of practically relevant magnitude.

Prior to the first experimental session, participants fill a general questionnaire to collect demographic data (gender, age, etc.), as well as subjective chronotype and perceived photosensitivity. They are then described the meaning of glare sensation votes (GSVs) based on time descriptors, and explained how to mark their glare sensation on a visual analogue scale (VAS). At each of the three sessions, the participant is also asked to fill in a short questionnaire to collect any other temporal or personal factor that could influence their glare response, such as their perceived level of fatigue, their food and caffeine ingestion, their

sleep quality, their mood, and their prior light exposure. The pre-test procedure is completed while the room is lit with a general lighting characterised by a CCT of 4000 K.

At the start of the procedure, the subject is invited to sit in front of the chamber, to adjust their chair height, and to place their head on a chinrest. The setup includes a dimmable light source placed at the centre of the apparatus within a circular orifice extending a solid angle of 0.009sr at the observer's eye. Another tunable luminaire, outside the field of view of the participant, maintains a background luminance of 65 cd/m^2. A pseudo-text is placed in front of the subject, with at vertical displacement of 15 degrees below the glare source. Since all other photometric and physical values are constant, the four IES-GI thresholds are achieved by setting, in a randomised order, the glare source at a luminance value of respectively 1627, 3860, 9150 and 21700 cd/m^2. At each session, the four thresholds are presented with the source and background luminance set at a CCT of either warm or cold light.

After having responded to the questionnaires, the participant is blindfolded for one minute, while the background and source luminaires are set to one of the two CCTs and the source luminance is adjusted to one of the IES-GI thresholds. The participant is given 30 seconds to perform a visual task, e.g. counting the number of occurrences of a certain letter within the pseudo text. After the task is completed, the participant is asked to mark their glare perception on the VAS. The participant is then blind-folded again for one minute, while the scene is toggled to next state, and the procedure is repeated for the remaining settings of CCTs and IES-GI values.

3. Results

The experimental tests will be concluded at the end of April. The responses on the VAS will be converted to percentage sensation score (PSS). For each CCT/ToD/GSV group, an initial analysis of variance (ANOVA) will be conducted to detect any significant differences in PSS across independent variables. Since the PSS data for each GI are nested across ToDs and CCTs, the data will be analysed via mixed-effect multilevel modelling.

4. Conclusions

Other than allowing to validate previous findings on the impacts of time of day and source spectrum on glare response, a more thorough characterisation of the mixed effect of these two independent variables will have significant relevance towards the definition of lighting strategies that could better respond to visual and non-visual needs throughout the day.

PP17

EVALUATION STRUCTURE ON PREFERENCE OF PAINTING'S APPEARANCE IN MUSEUM LIGHTING

Oe, Y.[1], Maeda, A.[1], Nagakoshi, H.[1] Takashima, M.[2], Mizokami, Y.[3] and Yoshizawa, N.[1]
[1] Tokyo University of Science, Chiba, JAPAN, [2] The National Museum of Western Art, Tokyo, JAPAN, [3] Chiba University, Chiba, JAPAN
yukioe@rs.tus.ac.jp

Abstract

1. Motivation, specific objective

Standards in museum lighting have been established to provide the minimum brightness necessary for viewing paintings, as well as to limit damage to exhibits. Currently, the CIE's index (CIE Technical Reports157) for museum lighting includes recommended illuminance and exposure levels that correspond to the responsiveness of the exhibits to light. However, to achieve an appropriate lighting environment with the minimum amount of light required, it is necessary to consider the luminance observed when light is reflected off the object and the luminance ratio of the painting surface to the background surface, which are more closely related to the brightness perceived by humans. Current standards do not adequately consider the brightness and visual quality of paintings as perceived by the viewer or the influence of the surrounding environment. Therefore, research focusing on the relationship between the preference for the visibility of paintings (hereinafter referred to as preference for visibility) and brightness is underway to create new lighting standards for museums. Our previous study found that the luminance ratio (defined as the average luminance of the painting surface divided by the average luminance of the background surface) has a strong influence on 'visibility preference'. The study also showed the possibility of predicting the painting 'brightness' using physical indices such as the illuminance of the painting surface and the luminance ratio, and furthermore, the 'preference for visibility' from the painting 'brightness'. With the ultimate goal of creating a new lighting standard for museums based on luminance, this study aimed to clarify the evaluation structure of visibility preference using a greater number of lighting conditions and replica paintings than in previous studies.

2. Methods

Five replica paintings were evaluated in the experimental room 5000 mm (depth) x 2900 mm (width) x 2400 mm (height), assuming an actual gallery in the museum. All surfaces of this space except the background surface were painted white (N9.5). Two types of lighting equipment were employed: (1) the ambient light (LED lighting: Ra=92, 3000K/3500K/3800K) to illuminate the entire space, and (2) the spotlight (LED lighting: Ra=97, 3000K) to illuminate the painting surfaces. The spotlight was equipped with a trimming cutter to illuminate only the painting surface. Three of five replica paintings were tested in the gallery for their original artwork in our previous study, so the correlated colour temperature of the room was adjusted by attaching a colour correction filter to the spotlight to match that of the gallery. The subjects were 20 university students (11 male and 9 female students) in their 20s with normal colour vision. The experimental conditions were three levels of illuminance (50 lx, 100 lx, 200 lx), eight levels of luminance ratio (minimum luminance ratio, 2/3, 1, 3, 6, 10, 15, 30), five paintings (mostly oil paintings), and the background wall surface colour was light grey (N8). In each painting, only luminance ratios that could be physically adjusted by spot and ambient lighting were selected, so the total number of experimental conditions was 111. The subject first adapted for 10 minutes after entering the room (illuminance of the painting surface: 100 lx). The experimenter set the conditions, and after 30 seconds of adaptation, the subject evaluated the appearance of the painting; then, this process was repeated. The order of presentation of the experimental conditions was randomised for each subject. Two types of evaluation were conducted using a 9-point bipolar scale. One was the evaluation of the

visibility for the entire painting surface, which was conducted on all paintings (13 items), and the other was for details on each painting.

3. Results

The analysis was conducted by adding the evaluation data of 10 paintings used in our previous study to the five paintings in which this experiment was conducted. The relationship between the overall evaluation items was confirmed using the mean values of the subjects' evaluations. It was found that the 'brightness of the painting' (hereinafter referred to as brightness) and 'preference for visibility' were proportional to each other up to a certain degree for all paintings, but preference tended to decrease when the painting surface was too bright. In addition, it was confirmed that 'appropriateness of brightness for the painting' (hereinafter referred to as appropriateness of brightness) had a stronger linear relationship with items related to the visibility of the painting (e.g. preference for the visibility) than 'brightness'. Based on the results of factor analysis (maximum likelihood estimation and Promax rotation) and partial correlation coefficients, a new path diagram was constructed by covariance structure analysis (by IBM SPSS Amos) using the 'appropriateness of brightness', and it was found that the GFI (Goodness of Fit Index) was >0.95 and the RMSEA (Root Mean Square Error of Approximation) was <0.1 for all 15 paintings, which was a sufficient level of fit. If the relationship between 'appropriateness of brightness' and 'brightness' can be clarified, it will be possible to predict 'preference for the visibility' through the evaluation structure including 'appropriateness of brightness' by estimating 'brightness' from the physical index.

4. Conclusions

This study was capable of constructing a good evaluation structure for all paintings used in the experiments, which leads from the 'appropriateness of brightness' to the 'visibility preference'. If we can predict the appropriate brightness of the painting when planning the lighting in a gallery, it will be possible to ensure a preference for the paintings' visibility. In the future, and this is going to be an objective of our next study, it will be necessary to investigate a method to predict the appropriate brightness for each painting based on its own characteristics, using the brightness of the painting surface predicted by physical indices such as the luminance ratio.

PP24

EFFECTS OF COLOURED LIGHTING ON HUMAN PHYSIOLOGICAL AND PSYCHOLOGICAL RESPONSES IN REAL AND VIRTUAL REALITY ENVIRONMENTS

Hao, S.M.[1], Wang, C.[1], Xing, Y.C.[1], Zhong, H.[2], Wang, J.[1],
[1] Beijing University of Civil engineering and Architecture, Beijing, CHINA, [2] Nottingham Trent University, Nottingham, UK
haoshimeng@bucea.edu.cn

Abstract

1. Motivation, specific objective

The impact of lighting on human well-being is widely recognized. Colored lighting, in particular, has been shown to have significant effects on human physiological and psychological responses. Previous research has demonstrated that colored lighting can influence human stress levels, emotions, and physiological responses such as heart rate, blood pressure, and cortisol levels. For example, red lighting has been linked to increased arousal and heart rate, while blue lighting has been associated with relaxation and calmness. In addition, colored lighting is an important element of virtual reality (VR) environments, which are increasingly utilized in fields such as gaming, education, and therapy. However, it remains unclear whether the effects of colored lighting on human responses are consistent across real and virtual environments. Therefore, the purpose of this study was to compare the effects of artificial lighting in real and virtual environments on participants' stress levels. By gaining a deeper understanding of the role of colored lighting in promoting well-being and enhancing human performance, this study may provide valuable insights to designers, architects, and researchers.

2. Methods

The study implemented two types of experimental environments, namely a virtual lighting environment and a real lighting environment. The real lighting environment, measuring 2.4 m x 2.1 m x 2.1 m, was established in a climatic chamber laboratory. The ceiling is equipped with a light box of the same size, comprising six LED light strips arranged evenly inside, which can be adjusted infinitely in terms of color hue, illumination, and color temperature. The floor and walls were covered with white diffuse reflective material. The virtual lighting environment was built to scale and with materials that strictly followed the real lighting environment. A head-mounted VR helmet was used to present the environment, and the Enscape® software served as the rendering engine.

Three monochromatic light environments of red, blue, and green were selected as the experimental group, while the white light environment served as the control group. To ensure consistency between the virtual and real scenes, chromaticity and illuminance meters were utilized to measure critical parameters. Moreover, based on a pre-experiment involving 86 subjects, the light parameters were further fine-tuned to minimize the differences in visual perception between the VR and real experimental scenes. Subsequently, 12 healthy university students (7 males and 5 females) aged 22 to 25 participated in the formal phase of the experiment. The participants were carefully screened to ensure that they did not suffer from color blindness or emotional disorders. Their dietary and routine activities were also strictly regulated on the day before and on the day of the experiment. The participants were assigned to both the real or virtual lighting environments, and their stress levels were assessed via self-assessment scales and various physiological data, including electrocardiogram (ECG), electrodermal activity (EDA), electroencephalogram (EEG), and salivary cortisol (SC) data.

3. Results

The research results indicate a consistent trend of heightened psychological stress in both physical (R) and digital (VR) illumination settings, with red lighting displaying the most significant influence, followed by white, green, and blue lighting, respectively. Additionally, a noteworthy elevation in heart rate variability (HRV) and electrodermal activity (EDA) was discernible across all lighting conditions. Notably, in the real red-light environment, the standard deviation of normal-to-normal intervals (SDNN) increased by over 81% in comparison to the baseline, while under blue light conditions, it only increased by 8.7%. In the VR environment, these values were 67% and 12.8%, respectively. Salivary cortisol levels did not exhibit significant differences, implying that it may not serve as a sensitive indicator under comparable experimental conditions. However, the study found no significant difference between the effects of real and virtual lighting environments on participants' stress levels.

4. Conclusions

In this study, we examined the impact of colored lighting on individuals' mental stress levels in both virtual reality and real environments. Our findings revealed a comparable order in the degree of influence of different colors on mental stress in both settings. Specifically, red light elicited the greatest stress response and the least relaxation effect, while blue light induced the least stress and maximum relaxation effect. In addition, certain physiological indicators such as HRV and EDA showed similar effects in both real and virtual lighting environments. Among the four light colors employed in the study, no significant statistical distinctions were apparent between the effects of real and virtual lighting environments on participants' stress levels. However, it should be noted that this conclusion is constrained to the light parameters investigated in this study. Further research is necessary to discern potential disparities in the physiological-psychological effects of lighting between virtual and real-world settings under varying light conditions.

PP25

SUSTAINABLE DAYLIGHTING TRAINING: THE NLITED PROJECT

Federica Giuliani[1], Natalia Sokol[2], **Valerio R.M. Lo Verso[3]**, Niko Gentile[4], Mandana Sarey Khanie[5], Federica Caffaro[6], Pimkamol Mattsson[4]
[1] University "Niccolò Cusano", Rome, ITALY, [2] Gdansk University of Technology, Gdansk, POLAND,[3] Politecnico di Torino, Turin, ITALY, [4] Lund University, Lund, SWEDEN, [5] Technical University of Denmark, Lyngby, DENMARK, [6] University "Roma Tre", Rome, ITALY,
natalia.sokol@pg.edu.pl

Abstract

1. Motivation, specific objective

The New Level of Integrated Techniques for Daylighting Education (NLITED) objective is to create a new and sustainable framework for daylight education for students and professionals within the built environment. The motivation behind this project was the results of the Daylight Knowledge in Europe (DAYKE) project, which confirmed the need for tailored daylight metrics and simulation training. The goal was to build a curriculum meeting the educational needs of society while reflecting the current state-of-the-art research on daylighting. The specific objective of NLTED was to develop educational content for the free eLearning platform with 28 e-modules. +30 teachers and experts provided the educational content. This paper offers a detailed framework of how educators create educational content and how over 600 students and professionals use it.

2. Methods

The methods to develop the educational content and curriculum for the e-platform included 14 workshops in 4 countries with 63 participants (37% from architectural and manufacturing companies, 5% from national bodies dealing with building legislation, and 58% from academic teaching staff) as well as interviews with the 32 partners (lighting and urban societies, practices and educational experts). The entry and final test taken by 600+ users monitor the platform's usage. Each block consists of 3-4 hours of pre-recorded e-modules which cover the knowledge on that specific topic with 'eTivities', which are interactive self-assessment exercises to help participants assess their progress in their understanding and the final test. This framework was designed to achieve the workload of 1 ECTS based on proper learning outcomes. The e-platform users also fill out an "e-module evaluation" (EE) based on a 4-point scale (1 = not at all agree; 4 = agree entirely). For the subsequent analyses, the responses are categorised into two groups: scores 1-2 = low agreement; scores 3-4 = high agreement.

Additionally, the educational content packed in 5 blocs with 28 pre-recorded modules, including 60+ case studies (the LMS platform format), is validated by hands-on experience, which was offered to 64 students attending two summer schools in 2022 and 2023. The schools were organised as seven days' events focusing on lighting appraisals, design, simulations and research methods based on real case scenarios. 20+ tutors provided the 40 hours of lectures and consultations.

3. Results

The educational content was formulated after analysing the 98 responses to the questionnaire distributed during 14 workshops with 63 experts and online through social media platforms. The final content is presented in five thematic areas ("blocks") that represent: (1) health; (2) daylighting design; (3) energy aspects; (4) daylight assessment; and (5) daylight simulation.

The NLITED eLearning platform launched on the 31st of January 2022 constituted five blocks with 28 e-modules. As for today, the most selected e-modules include subjects like benefits of daylight; visual comfort; preparation of the first daylight model with Ladybug tools in Rhino and Grasshopper; non-visual effects of light; assessment methods; beyond the metrics. The users are the least interested in e-modules on local standards and regulations, the LENI index, daylight measurements, simplified methods of daylight assessment, and modelling materials.

EE test results indicate that the low agreement scores (1-2) on the quality of the content remain relatively low (20% on average), never exceeding 40%. Most respondents judged the module they attended positively, attributing scores of 3 and 4.

The average module completion rate is 29%. It is higher than the 10% stated by typical online educational platforms. The number of enrolments is still increasing, and the dropout is lower than the values reported in the literature. The educational content offered on the platform is non-mandatory. The results indicate that the demand for specialised daylight knowledge is increasing.

4. Conclusions

This paper describes the framework of the NLITED project, which resulted in an eLearning platform on daylighting with 28 e-modules with +600 enrolled users since 2022 and 64 students attending summer schools with professionals. The educational content was designed in response to the results of 14 workshops with the experts. Since the e-platform launch, the most selected e-modules included benefits of daylight; visual comfort; daylight modelling with Ladybug tools in Rhino + Grasshopper; non-visual effects of light, indicating that the users of the platform are looking for particular educational content. The e-module 29% completion rate compared to the 10% reported in the literature of non-mandatory e-courses is promising for further developing specialised educational daylight education. The learners' responses indicate that the NLITED framework fills some of the needs of sustainable daylight education training.

PP26

THE INFLUENCE OF THE CONTENTS OF DYNAMIC WINDOW VIEW ON THE HEALING EFFECT OF PEOPLE IN ISOLATED, CONFINED AND EXTREME ENVIRONMENT

Tang, B.[1], Shi, J.[1], Zhang, X.[1]
[1] Tsinghua University, Beijing, CHINA
tb20@mails.tsinghua.edu.cn

Abstract

1. Motivation, specific objective

People working in isolated, confined and extreme (ICE for short) environments, such as aerospace, underwater, underground and polar environments, are required to face physical and psychological challenges with the lack of relations with the outside world. As a suitable healing method, window view system can provide contact with the outside world and improve physiology and psychological condition.

This study aims at the healing effect of different contents of dynamic window view on people in ICE environment. Different types of contents of window view were analyzed with their characteristics summarized. Filtered window views were then evaluated in the human factor experiment to explore the factors influencing the healing effect of window view.

2. Methods

The study started with the analysis of different contents of window views. The contents were assessed by the characteristics such as naturalness, movement, horizontal stratification of three layers (the sky, the middle layer of cityscape or natural elements, and the ground) and style. Fourteen kinds of window views were selected for further evaluation.

The evaluation experiment was conducted in a single office (about 2 m^2) with a LED screen playing videos as the window view. Thirty-two volunteers were required to wearing portable physiological equipment and experience the 14 kinds of window views in the office. Volunteers conducted five processes for each window view (about 10 minutes), including psychological evaluation, task pressure, healing of window view, re-evaluation, and relaxation.

During the experiment, Electrodermal Activity (EDA), Heart Rate Variability (HRV) and eye movement data were measured to evaluate the volunteer’s physical condition. At the same time, questionnaires including Positive and Negative Emotion Scale (PANAS), Perceptual Recovery Scale (PRS), Karolinska Sleep Scale (KSS) and Self-made subjective evaluation questionnaire of window view content were finished for their psychology. The characteristics of volunteers including age, gender and Big Five personality traits were investigated before the experiment to assess individual differences.

3. Results

Preliminary results show as follows:

(1) In general, the recovery trend enhanced in HRV and EDA with the increase in the proportion of nature.

(2) No matter from physiological or subjective evaluation data, the volunteers preferred window view with slight changes over those with more drastic changes.

(3) The volunteers marked some rendered window views higher than the actual ones.

(4) There was a significant correlation between window view preference and personality. For example, introverts preferred the material of rainy weather, while emotional subjects preferred the videos with more buildings.

4. Conclusions

Preliminary conclusions are as follows below.

In ICE environment:

(1) Dynamic window views with higher natural proportions have a better healing effect.

(2) People prefer window views with slight changes and well-prepared virtual window views.

(3) Personality can significantly affect people's feelings and preference for window view.

PP29

ENERGY SAVING WITHOUT COMPROMISING HUMAN COMFORT: A FIELD STUDY OF SMART LIGHTING IN OFFICE

Zhang, S.B., Su, H., Yang, B.
iLLab, Harbin Institute of Technology, Shenzhen, CHINA
yangbiao@hit.edu.cn

Abstract

1. Motivation, specific objective

Lighting accounts for 15% of global electricity consumption and contributes to 5% of global CO2 emissions, making it a significant factor in building sustainability. Following the initial phase of LED replacement, the lighting power density has been largely reduced. From human factors perspective, the visual environment has a profound impact on comfort and performance. However, the conflict between human comfort and energy savings becomes frequent, especially in public spaces such as open office. Expectations are put on the integration of smart lighting and human-centric lighting. As a result, there is a growing demand for an intelligent control system for the indoor environment. To investigate whether intelligent control systems are effective on energy usage and human comfort, a field study in which an intelligent transformation of about 200 m2 office space was conducted.

2. Methods

A field study was conducted to investigate the impact of an intelligent control system on office occupants. The experiment was carried out at an interior design company in Shenzhen, China from July 26th to December 8th, 2022. To eliminate the confounding variables, a Differences-in-Differences (DID) experimental design method was employed. Two open office spaces with similar dimensions and symmetrical layouts along the central axis were selected on the same floor. The orientation of the treated group was westward, while that of the control group was eastward. Two groups of office occupants were selected for the study: a treated group consisting of 29 occupants and a control group consisting of 40 occupants.

Intelligent transformation includes four parts: 1) Arrange sensors in the space, including air quality sensors, temperature and humidity sensors, and illuminance sensors, to perceive environmental parameters; 2) Arrange millimeter wave radar and infrared sensors to record occupancy behavior and smartmeters to record energy consumption data; 3) Install the Edge-Gateway to judge the current indoor environment information and user situation, then send instructions to the smart switch; 4) Install the wireless smart switch to control equipment, such as turning off the lights after ten minutes when sensing that people leave and turning on the lights immediately when people enter, etc.

To investigate the perceived impact of the intelligent control system on users, we conducted questionnaire surveys in both groups at all four stages to collect individual factors and perceived environmental conditions, including work performance, sleep quality, alertness, perceived stress, subjective vitality, physical quality, indoor environmental impressions, etc.

To avoid the Hawthorne effect and other interfering effects, the whole process of the experiment was divided into four stages: A-B-C-D. Stage A: The intelligent control system has not been installed; Stage B: The intelligent control system was installed, and the occupants were informed that it was running but actually not; Stage C: The intelligent control system was actually running; and Stage D: The intelligent control system has been stopped but the occupants have not been informed. Each stage lasted for about 45 days. For the control group, there is no intelligent transformation. The data was collected throughout all four stages, including the energy usage of each luminaire and air conditioner, user occupancy, and environment parameters (temperature, humidity, illuminance, and air quality). Based on the DID method, we measure the causal effect of the intervention by comparing the changes in outcomes between the treated and control groups before and after the intervention.

3. Results

Based on the analysis of 129 days of energy consumption and user behavior data from the experimental site, it was found that the electricity consumption of the experimental group was reduced to some extent after using intelligent strategies to control the lighting automatically based on occupancy detection. The average daily electricity consumption before the system was turned on was about 77.2 kWh, and it dropped to 67 kWh after it was turned on, reducing the lighting energy consumption by about 13.2%.

The results of the questionnaire survey show that, compared with stage A, the perceived environmental conditions and environmental utility of stage C have significantly improved ($p<0.05$), and the difference between stage B and stage C is not significant. The Hawthorne effect was found during the experiment.

4. Conclusions

This study is based on the intelligent transformation of real scenarios and performs real-time adjustment by analyzing human behavior and environmental information. It uses the DID method to analyze actual energy consumption and user perception and explore the energy-saving potential and environmental comfort impact of intelligent transformation. The results show that effective control strategies can significantly reduce electricity consumption (13.2%) without compromising comfort.

Further refinement of existing strategies includes two points: 1) Due to the working schedule of the company, the working hours of employees were flexible and dispersed, existing luminaires cannot be adjusted individually; 2) Natural light was not fully utilized for lighting but instead curtains were always closed. Through the adoption of refined lighting control and the integrative lighting system, smart lighting has greater potential in energy-saving and human comfort.

PP13

THE EFFECT OF LIGHT INTERVENTION ON EMOTION BASED ON THE COMBINED IMPACT OF VISUAL PREFERENCE AND NON-VISUAL INFLUENCE

Zhou， L.[1,2,4], Li, N.[1,3], Lin, Y.[1,2,3,4]

[1]Institute for Electric Light Sources, School of Information Science and Technology, Fudan University, Shanghai 200438, CHINA, [2]Institute for Six-sector Economy, Fudan University, Shanghai 200433, CHINA, [3]Human Phenome Institute, Fudan University, Shanghai 201203, CHINA, [4]Intelligent Vision and Human Factor Engineering Center, Shanghai 201306, CHINA

ydlin@fudan.edu.cn

Abstract

1. Motivation, specific objective

The light environment, as an important external stimulus, has a moderating effect on emotion regulation, which has been demonstrated in both clinical patients and healthy subjects. However the findings of relevant studies are not fully consistent in the quantification of light parameters, especially on which spectrum is suitable for this application. Therefore，it is of interest to find out which charateristics of light intervention is important for adjusting emotion based on non-vision influence.

2. Methods

In the previous studies, systematic evaluations of light intervention on emotion were conducted, and the meta-analysis result with a large sample revealed that, preference for lighting and light circadian stimulus, were associated with emotion regulation. In this study, we conducted a light intervention experiment with different cross combinations of preference levels and circadian stimulation levels as independent variables, and quantified individuals' emotion and cognition by measuring negative cognitive bias, heart rate variability and subjective mood scales to explore the effect of light on negative emotion and cognitive regulation in individuals with depressive tendencies.

3. Results

The results showed that light condition with high preference and high circadian stimulation significantly modulated the negative emotions ($p<0.001$) and had a significant positive moderating effect on negative cognitive biases ($p=0.017$). Neither the lighting groups with low circadian stimulation nor the low preference had significant influence on the negative emotions regulation.

4. Conclusions

Based on the results of this study, only light that satisfies both visual preference and high circadian stimulation levels can positively modulate the emotion in individuals with depressive tendencies, which provides design guidance for lighting therapy as well as artificial illumination for special places.

Session PS3
Presented Posters (D2/D4)
Monday, September 18, 15:20-16:05

PP7

LIGHTING ENVIRONMENT IN URBAN PARKLANDS AND GARDENS: CASE MODELS FOR BRATISLAVA

Gasparovsky, D., Raditschova, J., Dubnicka, R., Janiga, P.[1]
[1] Slovak University of Technology, Bratislava, SLOVAKIA
dionyz.gasparovsky@stuba.sk

Abstract

1. Motivation, specific objective

Differentiation of recommended limits of relevant lighting parameters for assessment of obtrusive light from outdoor lighting installations is based on environmental lighting zones established in the Technical Report CIE 150. The zoning system ranges from E0 for intrinsically dark lighting environments such as protected areas and national parks, through E1 and E2 for relatively unhabited or sparsely inhabited rural areas, respectively, up to E3 and E4 for urban settlements. Distinction of the zones is, however, uneasy in practical application because the zoning system does not distinguish between diversity of adverse effects of lighting on the environment – whether it concerns astronomical observations, fauna and flora or humans (inhabitants, visitors, sightseers, road users). The same applies to application of the limiting lighting parameters using the same zoning system, such as upward light ratio of luminaires ULR and upward flux ratio of installation UFR, vertical illuminance on properties, average surface luminance, luminous intensity of luminaires in designated direction, and veliling luminance and threshold increment from non-road lighting installations. In principle, none of the above mentioned parameters is suitable for assessment of obtrusive light with respect to animals and plants, not to forget that large differences can be obviously expected here due to variety of species. Impact of artificial lighting on the natural environment is in scope of the CIE Technical Committee TC 4-61, aiming to develop the much needed guidance and recommendations.

Urban settlements like towns and cities have their own internal structure comprising e.g. city centres, residential areas, commercial areas, industrial zones and green zones – all having very specific character regarding outdoor lighting, user needs, environment etc. Urban lighting masterplan is a document to analyze this structure and to establish framework requirements on lighting. Environmental considerations are indispensary in developing a masterplan, as dealt in the CIE 234:2019 Technical Report. It is clear that the zoning system of CIE 150 is inapplicable to that internal structure as it all comes under E3 or E4. Refinement with respect to different city zones is needeed. In particular, green zones such as parks, gardens, cemeteries etc. are quiet islands surrounded by settlements, sometimes with rush traffic and hectic life. Urban greeneries are vulnerable habitats, natural homes of typical plants and animals. This paper aims to study environmental and lighting conditions in urban parklands and gardens, hence to contribute to the investigation of obtrusive light with respect to fauna and flora.

2. Methods

This paper aims to publish partial results of the investigation of obtrusive light in urban parks, gardens, cemeteries and similar mid- to large-size greeneries, showcasing typical parameters of the lighting environment for two case models in Bratislava. Both the Medical garden and Janko Král's park are rather larger city parks located in or nearby the city centre, i. e. with a busy life around. Lighting conditions are studied with two approaches: modelling and measurement. Model of the parks is built in the Dialux lighting software allowing to carry out the desired calculations with any lighting arrangement (current/installed, optimized to footpath lighting, optimized to the least spill light etc.), any technology (white globe luminaires, non-cut-off sodium lamp luminaires, modern cut-off LED luminaires), and any parameters of interest. The models reflect the real situation in a spring – summer period (regarding the foliage), incorporating all trees, bushes, flowers, grass as the plants, statues, fountans, furbishment etc. Parameters of interest amongst others comprise horizontal illuminance on

footpaths, grass strips aside to footpaths in different distances, vertical illuminances in different distances from footpahts and in different heights as well as illuminance on tree crowns or other plants. Reflectance of the objects in parks used for modelling is based on in-situ measurements, thus well represent the real values. Measurements of lighting parameters in real conditions are carried out in order to support the calculation models. Aim of the study is to provide description of the lighting environment for further investigation of the effects of obtrusive light in such habitats.

3. Results

Results are currently available for the Medical garden; for the Janko Král's park the measurements will be carried out in course of spring 2023 (leaf and plant foliage), having fresh results available for the full-text paper. Interim results showed that with old-fashioned lighting systems the illuminance on green parts is in several luxes and gradiently drops downs to tenths of luxes within 5 m distance from a lighting pole, comparable to illumination from the moon. All higher plants (bushes, trees) are usually located behind that distance. Distribution of illuminances strongly depends on the technology implemented, the worse for white globes, much better for LED luminaires with proper distribution of its luminous flux. More detailed results with a graphical interpretation will be presented in the full-text paper.

4. Conclusions

Properly designed park lighting aids to mitigate illuminance on plants and persumably to reduce or even avoid adverse effects on the plants themselves as well as animals obscured by green curtains. Intrusive light from outer lighting installations (typically floodlights) can have significant impact when directed towards the park. Time management of lighting is of crucial importance. For application of the results further considerations on behaviour of the plants and animals in urban environments will be needed, however, this is beyond the scope of this study.

PP20

INVESTIGATING THE EVOLUTION OF ROAD SURFACE DESCRIPTORS ACCORDING TO OBSERVATION ANGLES USING A DATABASE OF THE REFLECTION PROPERTIES OF URBAN MATERIALS

Saint-Jacques, E., Bremond, R., Eymond, F., Morvan, K.
Université Gustave Eiffel, COSYS, PICS-L, F-77454 Marne-la-Vallée Cedex 2, FRANCE
enoch.saint-jacques@univ-eiffel.fr

Abstract

1. Motivation, specific objective

Reflection properties of the pavement have to be considered when designing road lighting installations. These properties depend on the material and on the 3D geometry texture; they can be specified by means of a set of luminance coefficients *q,* which vary both with the lighting and viewing directions and is thus also called the Bidirectional Reflectance Distribution Function (BRDF). Whole BRDF measurements are time-consuming and are thus rarely used per se. Yet, current road surface classifications used for road lighting designs and performance computations depend on parameters Q0 and S1 which are based on outdated surface characteristics (from the 1960's) and consider only the motorist's point of view (one single observation angle). As literature confirms that CIE's r-tables may no longer be representative of current road surfaces, the additional need to consider other users' point of view arises. Indeed, in urban areas, motorists do not look the road ahead at 1° but rather around 3°, pedestrians look at around 10° and visually impaired people may observe at 45°.

The need of whole BRDF data, including for all lighting and observation angles thus becomes increasingly necessary. This paper proposes to use a recently released open source database of measured whole BRDF by means of our in-lab gonioreflectometer in order to investigate the performance of road surface descriptors, such as the degree of lightness Q0 and the specularity factor S1 for different observation angles and their prediction from a few measured r-tables at given observation angles.

2. Methods

Our in-lab gonioreflectometer, even though it was specifically designed for public lighting applications, was utilized to measure whole BRDF for realistic rendering in virtual reality applications. A database of measured BRDF of some 50 various urban materials (granite, gravel, wood, and road surfaces) was constituted for this purpose. In this database, there were around 20 road surfaces of different types, such as porous asphalt, light porous asphalt, asphalt concrete or ultra-thin asphalt concrete. For theses surfaces, we have additionally measured r-tables for 1° observation angle but also for some other observation angles (e.g. 10° for the pedestrian's point of view).

From the measured BRDF for virtual reality application, we computed, by interpolation and extrapolation, the r-tables for different observation angles, and derived both the parameters Q0 (the degree of lightness) and S1 (the specularity factor) from these interpolated r-tables.

3. Results

We computed the root mean square error between interpolated r-tables and measured ones for the road surfaces of the database. We also present the computed Q0 and S1 indexes from interpolated r-tables at observation angles from 1° to 90°, derived from the whole BRDF of around 20 road surfaces of the database and compare them to the Q0 and S1 computed from the measured r-tables at a few observation angles (e.g. 1° and 10°). Results show that in general, the higher the observation angle, the smaller the relative error, both of Q0 and S1

(less than 10% at 10° of observation). The relative error of Q0 and S1 is less than 10% for some types of road surfaces, such as the asphalt concrete and seems dependent on the type and composition of road surfaces.

Moreover, from a limited number of measured r-tables at a few observation angles, one may predict the evolution pattern of Q0 and S1 at all other observation angles, thus making the need of having whole measured BRDF less critical for road classifications and observer-dependent performance. A few models of Q0 and S1 function of the observation angles are proposed.

4. Conclusions

From a database of BRDF of surfaces measured by means of our in-lab gonioreflectometer and aimed for virtual reality application, we proposed, in this paper, to extend its use for public lighting application. From r-tables measured at a few observation angles, we proposed a method to derive the classical road surface descriptors Q0 and S1 at other observation angles. Future work involves improving the evolution models of Q0 and S1 according to observation angles for every type of road surfaces. Another perspective comprises computing Q0 and S1 directly from available measured BRDF at each observation angle, without needing to first interpolate at the standard r-table geometries. This work would enable us, thanks to BRDF not necessarily measured for public lighting purpose, to use them to predict the influence of the road surface at viewing angles other than the motorist's 1°, in order to specify lighting for applications in the fields of automotive and public lighting (adaptive lighting, observation from pedestrians, visually impaired people, truck drivers, aircraft, etc.).

PP22

CHARACTERISATION OF ROAD REFLECTION IN RELATION TO VEHICLE HEADLAMP ILLUMINATION

Schulze, C.
Technische Universität Dresden, Lighting and Vision Lab, Dresden, GERMANY
christoph.schulze@tu-dresden.de

Abstract

1. Motivation, specific objective

According to Joint Technical Report CIE/PIARC 66 and Technical Report CIE 144, characterizing the reflectance of roads includes several photometric use cases. Reflection in relation to vehicle headlamp illumination is one of these. There are only a few studies on this in the literature. Some of these are already several decades old. Irrespective of this, the photometric characterization of road surfaces is mostly carried out for road and tunnel lighting. Consequently, mainly the corresponding characteristic values are discussed (r-table, Q0: parameter of lightness and S1: specular factor).

This paper is devoted to some hitherto little considered issues around the reflection of roads lit by vehicle lighting. The following questions are addressed:

What is the relationship between the reflection of roads with respect to vehicle lighting and the characterization for road and tunnel lighting?

How do today's road surfaces behave in reflection with different illumination and observation geometry related to illumination by vehicle headlights?

In this context, it is also important to clarify whether brighter roads (in the sense of more reflective) under one aspect are also brighter roads under the other aspect. It is also necessary to address the question of whether the luminance coefficient can be assumed to be independent of the distance of observation for a given vehicle. But the question of observer height is also significant. Do people in trucks systematically experience brighter or darker roads compared to people in cars?

2. Methods

To answer the questions, reflectance measurements were made in the photometric laboratory on 57 different road surfaces (laboratory samples and core samples of different construction methods). Measurements of reflection with respect to street and tunnel lighting were made using a goniophotometer (entire r-table measured). A setup on the optical bench with a scale of 1:10 was used to measure the reflection when illuminated by vehicle headlamp.

Luminance coefficients were determined for combinations of lamp heights hs=0.65m and 0.85m and observation heights in the steps ha=1.2m, 1.5m and 2.25m at distances d=20m, 35m, 50m, 65m and 80m. For geometrical reasons, the luminance coefficients could not be measured in the combination hs=0.85m and ha=1.2m. In addition, the luminance coefficient was measured at hs=0.65m and ha=1.2m at distance d=30m, which is referred to as R_L in the literature. R_L is primarily used to characterize the night reflection of road markings.

3. Results

The results reveal interesting findings. For the relationship between characterization for street lighting and illumination by vehicle headlights, there is a correlation between Q0 and R_L of r=0.71. The representation as a cloud of points proves a less systematic correlation. But there is a negative correlation between R_L and S1, which can be interpreted more clearly. It can be described approximately by an exponential function. Furthermore, there is a significant influence of the observation distance. The luminance coefficient decreases in the range of observation distance 20m to 80m by about 20% on average of all investigated samples. A

significant influence of the observer height was also proven. It is greater than the influence of the observation distance. For example, in the comparison ha=1.2 versus 2.25m at hs=0.65m, the luminance coefficients decrease by more than one third. However, the influence of the observer height interacts with the headlight height. The described effect is smaller for higher headlights.

4. Conclusions

The reflection of roads for headlamp illumination is related to the parameters of reflection for road and tunnel lighting. In particular, highly specular surfaces (standard reflectance classes C2) show systematically lower reflectance for illumination by headlamps of motor vehicles. The extent to which the functional relationship found can be generalized should be clarified by further investigations. In contrast, there is no particularly close correlation with the mean luminance coefficient Q0, which is generally used to distinguish between road surfaces with different reflectance.

Many roads are illuminated by street lighting or tunnel lighting and must therefore undoubtedly be characterized mainly for this application. For the reflection of roads not illuminated in this way, the description based on mean luminance coefficients (e.g. Qd or Q0) and specular reflectance (S1) offers only a conditionally suitable characterization. At the same time, it becomes apparent that optimization of the road surface reflectance seems possible depending on the application, but that a cross-application property "bright or highly reflective road surface" does not seem to exist apart from individual examples.

The road reflection of vehicle headlamp illumination is systematically related to the illumination and observation geometry. Specifically, the reflection decreases significantly with increasing observation distance and observation height. Thus, there is a constellation that is systematically unfavorable in terms of visibility under nighttime conditions when illuminated by motor vehicle headlights. With increasing distance, the illuminance produced by the headlights decreases. In addition, the reflection also decreases. From vehicles with greater eye point height (e.g. trucks), illumination results in a systematically darker road (identical headlights assumed).

In order to be able to use the results also in current discussions about video-based driver assistance systems (relation to the contrast of road markings), the measurement of corresponding reflectance values of road markings is suggested. And when it comes to characterizing the visibility conditions in road traffic at night, the question of road reflection from the viewpoint of oncoming traffic also arises.

PP28

EXPLORE THE RELATIONSHIP BETWEEN AMBIENT LIGHT AND CYCLING FREQUENCY AND SPEED

Wei, L.[1], Kobav, M. B.[1]
[1] University of Ljubljana, Ljubljana, SLOVENIA
Lanlan.wei@fe.uni-lj.si

Abstract

This study presents the results of an analysis of the influence of ambient lighting on the frequency and speed of cycling, using data from on-site records collected over a five-year period. The approach used an odds ratio analysis to estimate the relationship between darkness and bicycling frequency compared to daylight while controlling for potential confounding factors. Furthermore, the study compared the speeds of cyclists during the day and at night, as well as at four different locations with varying levels of road lighting, to investigate the correlation between lighting levels and bicycling speed.

1. Motivation, specific objective

The study was conducted in Ljubljana to investigate the impact of ambient lighting on the frequency and speed of cycling. Ljubljana is renowned as one of the top 20 bicycle-friendly cities globally, with a well-established network of 306 kilometres of bike paths. In order to collect data on cycling activity, four automatic traffic counters were installed along the paths leading to the city centre since 2015. These counters record bicycle traffic in both directions and are passed by over three million cyclists annually. For the study, data was collected by these counters over the past five years, specifically from January 1, 2016, to December 31, 2020. The findings of this study may have implications for urban planning and public health.

2. Methods

The paper analyses the effect of ambient lighting on the frequency and speed of cycling using data from an entire year. The study uses an odds ratio analysis to estimate the relationship between darkness and cycling frequency compared to daylight.

To calculate the odds ratio, the frequency of cyclists during the same hour (17:00-17:59) of the day (A) and darkness (B) is summed, and the ratio between these two is calculated (A/B). This ratio is then compared to the ratio of the summed frequencies during the same two periods of the year but for the two control hours (15:00–15:59 and 21:00–21:59, C and D). To determine the influence of lighting on frequency, the odds ratio between the case hour and control hour was calculated as (A/B)/(C/D).

Similarly, the speed of the cyclists was calculated by averaging the speed recordings from both the case hour and control hour group data. The same approach was used to examine the speed odds ratio across different light conditions (daytime and dark time, the four distinct levels under road lighting which the average horizontal illuminance from 5.5 lux to 10.5 lux).

3. Results

The results show that ambient light has a significant effect on cycling frequency, while road lighting level has a small effect on cycling speed. In addition, subtle changes in frequency patterns were observed in some months, possibly due to the COVID-19 pandemic.

4. Conclusions

By using a large data set, this study should provide a comprehensive understanding of the relationship between ambient lighting conditions and cycling behaviour. The results of this study may have important implications for urban planning and public health and provide valuable insights for future research in this area.

PP5

PRELIMINARY STUDY FOR TRACEABILITY ON SPECULAR GLOSS

Ferrero, A.[1], Gevaux, L.[2], Rastgou, M.[3], Jaanimets, M.[4], Jurgo, I.[5], Manoocheri, F.[3], Kübarsepp, T.[4], Nilsson, A.[6], Szajna, G.[5], Obein, G.[2]
[1] Instituto de Óptica "Daza de Valdés", Agencia Estatal Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, [2] Conservatoire national des arts et métiers, La Plaine St Denis, FRANCE, [3] Metrology Research Institute, Aalto University, FINLAND, [4] AS Metrosert, Tallinn, ESTONIA, [5] Central Office of Measures, Warsaw, POLAND, [6] NCS Colour AB, Stockholm, SWEDEN
alejandro.ferrero@csic.es

Abstract

1. Motivation, specific objective

The measurement of specular gloss has been standardized as described in the Standard EN ISO 2813 and other national equivalents as, for instance, the ASTM D523. According to EN ISO 2813, the gloss value is defined as the ''ratio multiplied by 100 of luminous flux reflected from a specimen to that reflected by a glass surface with a refractive index of 1.567 at a wavelength of 587.6 nm in specular direction for a specified reflection angle and specified aperture angles of light source and detector". However, this definition does not specify unequivocally the quantity to be measured, and, in consequence, the Standard provides additional conditions to the glossmeters regarding the illuminant (CIE illuminant C) and the geometries of illumination and collection.

According to the definition, the gloss value can be obtained from reflectance measurements with the geometry defined by the Standard, or by measuring the bidirectional reflectance distribution function (BRDF) around the specular direction, with high angular resolution, as that provided by conoscopic systems. We think that this approach would allow National Metrology Institutes (NMIs) and Designated Institutes (DIs) to provide traceability to the measurement of specular gloss without the need of using the external reference glass plate required by the Standard.

The specific objective of this work is to test this approach for measuring gloss, as a preliminary step towards the provision of traceability to gloss measurements by NMIs and DIs.

2. Methods

Gloss measurements of four samples, covering the gloss range from 20 GU to 93 GU (gloss units), were carried out with different measuring systems and procedures, by the Aalto University (Aalto), *Conservatoire national des arts et métiers* (LNE-CNAM), *Agencia Estatal Consejo Superior de Investigaciones Científicas* (CSIC), Central Office of Measures (GUM) and Metrosert.

Among the measuring systems, three commercial available gloss meters were used: (1) The spectro-guide sphere gloss S, from BYK Gardner, with white calibration standard provided by the manufacturer as a reference sample; (2) the Haze-Gloss 4601, manufactured Byk-Gardner, with certified high gloss black standard manufactured by Byk-Gardner as a reference sample.with traceability to the NRC; and (3) the Rhopoint IQ 20°/60°, with the BYK Gardner semigloss 60 as reference sample. These measurements are supposed to be a good reference with respect to the commercial instruments.

As alternative approach based on the reflectance measurement, the relative bidirectional reflectance around the specular direction was measured with a calibrated camera in conoscopic mode, and the variation of this reflectance with the polar and azimuth angle was obtained. This was used to obtain by integration the directional-conical reflectance at the specified geometry defined in the standard. This is an absolute method and does not require a standard artefact as reference sample.

As another alternative procedure we tested measuring the reflectance without the angular resolution provided by the camera in the previous method. Instead, specular reflectance measurements were carried out while restricting the source geometry and expanding receptor aperture to satisfy the gloss standard.

The results from the measuring systems and procedures were compared and analyzed in terms of consistency with respect a reference value calculated as the weighted average of all measurements. The weighting value for each measurement is the square of the inverse of the corresponding reported uncertainty. This information allows conceptual or systematic error to be identified from the alternative absolute methods here evaluated.

3. Results

The measurements with the commercial glossmeters are compatible with the calculated reference value within a confidence interval of 95 % (approximately ± 2 GU).

The measurements with other non-commercial instruments, based on the assessment of the reflectance provide slightly different results. They are still compatible with the reference value for the two glossiest samples, but there are some inconsistencies for the other samples. The reasons of these inconsistencies are being studied in the moment of this communication.

The nominal gloss value and the gloss values given by the provider of the samples also are slightly incompatible with our reference for some gloss levels. In general, the larger the gloss of the sample, the closer are the gloss values measured by the different systems of the present study.

4. Conclusions

This preliminary study towards providing traceability to specular gloss measurements has shown the feasibility of the two absolute methods here proposed. The main difficulty seems to be the realization of the exact geometrical conditions specified by the Standard in the measurement of reflectance.

PP8

METHOD FOR TRACEABILITY OF MULTISCALE BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION MEASUREMENTS

Gevaux L.[1], Saha D.[1], Morvan K.[1], Frisvad J. R.[2], Obein G.[1]
[1] LNE-CNAM (EA 2367), La Plaine St Denis, FRANCE
[2] Technical University of Denmark, Anker Engelundsvej 101, 2800 Kongens Lyngby, DENMARK
lou.gevaux@lecnam.net

Abstract

1. Motivation, specific objective

The need for measurements of the Bidirectional Reflectance Distribution Function (BRDF) at several scales, i.e. from the micrometric scale to the centimeter scale, is recently growing. It comes from the need to characterize and evaluate the appearance of very small objects for quality control, as well as from the need to measure and model objects whose appearance has a multiscale aspect for applications in virtual rendering and 3D printing. Dedicated goniospectrophotometers have been developped to meet this need and the traceability of these instruments must be established.

The classic method to calibrated a goniospectrophotometer usually consists in measuring a white diffuser used as calibration standard. But this method does not apply to micrometric BRDF scale because the reflectance properties of these diffusers aren't invariant to scale variations. Indeed, a proper multiscale calibration standard must keep invariant its BRDF at all tested scales. Consequently it must follow three criteria: 1) Surface topology must not change the BRDF at all scales. Samples with a roughness that is not negligeable at the measurement scale are not eligible. 2) Transluscency of the sample must be negligible at all scales to avoid the translucent blurring effect. At very small scales, many materials are actually translucent and cannot be used. 3) Light surface reflection cannot be too specular to keep the reflectance out of the specular direction high enough to be measured by the device. Therefore, samples with very smooth surfaces or metallic samples (which could be good candidates because they are not translucent) are not adapted.

Those three criteria are very difficult to fullfill at the same time, and we haven't found a suitable sample yet. Consequently, the establishment of BRDF traceability using methods relying on measuring the same standard sample at various scales and expecting similar results cannot be applied here, and an alternative method must be implemented.

The objectives of our work is to develop a method to extend the traceability of BRDF to multi-scale measurements and propose adapted samples.

2. Method

The validation method relies on the measurement of matt samples presenting a periodical texture that is small according to the beam multiscale size and a structure that limits the issues linked to translucency. More concretely, those samples are made of black plexiglass onto which holes were periodically drilled, then filled with white resin and sanded to obtain a diffusing surface that presents white disks on a black background. In our case, we manufactured samples drilling holes of diameter 300 µm with a period of 600 µm.

When measuring the BRDF of such sample in an underfilled configuration (the illuminated area is smaller than the collection area), the result depends on the size and location of the illuminated area. The size of the illuminated area can be easily measured, however, its exact location is difficult to control, given the small size of the sample's structure (300 µm white disks). To tackle this issue, the BRDF measurements are repeated at regular intervals on the sample, with intervals smaller than the period of the sample structure.

The periodic scan of the sample yields BRDF measurements with periodic variations. The period of these variations depends on the structure of the sample. The contrast of these variations depends on the size of the illuminated area: a small illuminated area yields a high contrast, while a large illuminated area yields a low contrast. The actual BRDF of the sample corresponds to the average value measured on the surface, and a multiscale setup is validated if the same average value is found at the different scales.

3. Results

A setup for directional reflectance measurement including motorized translation stages was developped to perform periodic measurements of the BRDF in a ($\theta\mathbf{i}$ = 0°: $\theta\mathbf{r}$ = 15°) geometry with illuminated areas corresponding to disks of diameters ranging from 1 mm to 10 mm. The motorized translation stages allow us to control the position of the sample with a micrometric resolution.

For small enough illuminated areas, a single line scan show periodic BRDF with a period of 599 µm, which is very close to the theoretical period of the samples (600 µm). The proceedings paper will include a comparison between experimental results and simulations implemented in MatLab to validate the approach.

The period of the structure limits the smallest scale that can be validated. In our case, with samples presenting a period of 600 µm over a 4 cm^2 area, BRDF measurements can be validated on areas ranging from 600 µm to 40 mm diameter. We believe that this concept can be extended to smaller scale providing that one can drill smaller holes.

4. Conclusions

A method suitable for the validation of multiscale BRDF measurement setups is proposed. It relies on the periodic measurement of samples presenting a regular structure that are inexpensive to produce and easy to model. The method has been conceived for BRDF measurement performed in an underfilled configuration, but can also be applied to setups measuring BRDF in an overfill configuration.

PP10

LED LIFETIME TESTS FOR CIRCUIT SIMULATION MODELLING

Hegedüs, J.[1], Hantos, G.[1], Poppe, A.[1], Kovács, R.[1], Bojta, P.[1], Harsányi, G.[1]
[1] Budapest University of Technology and Economics, Faculty of Electrical Engineering and Informatics, Budapest, HUNGARY
hegedus.janos@vik.bme.hu

Abstract

1. Motivation, specific objective

The latest generation of computer-aided design is the so-called Industry 4.0, which simulates the entire system using digital models or the so-called digital twins of the individual components. The many advantages of the method could best be presented with the image where the designer working with the advanced technologies no longer holds before his examining eyes a real board model of the device to be designed, but rather a digital image of it that is perfectly lifelike in every respect. With the help of this, not only the design costs and the time to market can be significantly reduced, but also aspects of the final product can be outlined, which otherwise would not have been possible in the case of the prototype laid on the design table. Such aspects can be, for example, extreme operating conditions and long-term reliability issues, the testing of which is otherwise extremely demanding of time, economic and human resources. However, it must be remembered that no computer simulation can be more accurate than the model on which it is based. For this very reason, research efforts investigating the appropriate modelling possibilities of light sources are extremely important. Among these modelling works, our institution is currently active in researching lifetime circuit simulation LED models.

In addition to the effects of a pulse width modulation (PWM) based driving on LED reliability, our latest tests are also related to relative humidity. Thermally activated aging processes in LEDs can be described very well by the Arrhenius-type lifetime model and temperature-dependent acceleration factors can be calculated: lifetime predictions can be estimated with accelerated lifetime tests. This is, however, a solely temperature-based model not calculating with other environmental circumstances, like chemical (humidity) parameters. LEDs are soon representing the majority of lighting devices worldwide even in harsh environment applications: besides outdoor and automotive illumination, even the household (kitchen, bathroom, cellar) may represent extreme humidity variations for these devices thus, their reliability behaviour in such circumstances should be better understood. The absorption of moisture can induce hygroscopic swelling in the LED packaging materials such as molding polymer, die attachment, and epoxy and polysiloxane packaging materials. The hygroscopic swelling linearly increases with moisture content. The different levels of swelling induce hygroscopic stress in the package, thereby inducing delamination. As moisture continues to enter into the die attach material, delamination at the die-attach will occur and thus increase the thermal resistance of the dice, and reduce the lumen output, leading also parallel corrosion/migration processes.

2. Methods

The most widely accepted method of life testing of power LEDs is described in the IES LM-80 Lighting Measurement and Testing document. There are several additions to reliability tests performed at constant forward current and ambient temperature to test operating parameters, such as, for example, increasing the relative humidity or using a drive based on pulse width modulation instead of a constant current drive. These testing procedures can be perfectly combined with the non-destructive multi-domain LED characterization procedure based on the JEDEC JESD51-5x family of standards, during which the electrical, optical and thermal operation of the encased LED is examined together. In the final article to be submitted, on the one hand, we would like to present an LED reliability test in which the tested LEDs were driven with PWM control at different frequencies, in order to investigate to what extent the different frequencies impair the thermal conductivity of the LED case.

The waterproofness is typically checked in the initial stage of the products and may change during the aging of the applied materials. Even waterproof constructions may lose from these characteristics and become permeable for water molecules at high humidity levels after some period of work. Even hermetically closed inert gas-filled constructions may fail from moisture precipitation if the internal component surfaces or the inert gas filler itself contained some amount of water molecules before closing the construction. Highly accelerated stress test (HAST) and thermal humidity bias (THB) tests with surface condensation life tests can help to reveal potential failure problems in these cases. In the experimental work these environmental aging tests were performed, device thermal and optical parameter changes were followed, and failed devices were subject to detailed failure analysis performed with optical, X-ray, Scanning Acoustic and Scanning Electron Microscope.

3. Results

The PWM-based test revealed that modulation below a characteristic time constant of the LED case, i.e. above the corresponding frequency, degrades the thermal conductivity of the LED case to a lesser extent. In addition, during our combined electrical, optical and thermal tests, we experienced a phenomenon related to the browning of the lens material, which could even falsify the test results related to LED aging.

The results demonstrated that high humidity level means a severe threatening issue for LEDs. Aging processes and their „speed" were identified in order to estimate real lifetimes. New aging models were suggested for better description. Some of them were already mentioned by the literature, but the exact process description needed fine-tuning.

4. Conclusions

Future smart illuminating systems should apply the optimization of the operating parameters based on models of the aging processes in LEDs. After collecting the necessary amount of experimental results, a control system can be developed for the smart lighting systems to improve their climatic reliability. Pulse width modulation of the LEDs should be performed above the frequency value characteristic to the thermal time constants of the LED case, otherwise thermal cycling may cause a significant increase of the thermal resistance and thus an elevated operating temperature of the device. High humidity conditions generally result in the formation of condensed moisture that can be evaporated at temperatures elevated only by a few degrees above the environment. LEDs are operating at temperatures higher than the environmental level, therefore, the moisture is more likely to condense on LEDs out of operation. With humidity level monitoring performed by appropriate sensing elements, heating purpose operation periods can control the moisture condensation keeping the surfaces clean and avoiding failures.

PP14

TEMPORAL LIGHT ARTEFACT METRICS OF COMMERCIAL LED LAMPS

Mantela, V.[1], Nordlund, R.[1], Askola, J.[1], Kärhä, P.[1], Ikonen, E.[1,2]
[1] Metrology Research Institute, Aalto University, FINLAND, [2] VTT MIKES, VTT Technical Research Centre of Finland Ltd, FINLAND
ville.mantela@aalto.fi

Abstract

1. Motivation, specific objective

LED sources exhibit different Temporal Light Modulation (TLM) behavior compared to the incandescent lamps due to their different operating principles. This can cause visible effects, known as Temporal Light Artefacts (TLA), which may be detrimental to human health. Because of this, EU Ecodesign regulation in 2021 set restrictions for two TLA metrics, short-term flicker severity index (P_{st}^{LM}) and stroboscopic visibility measure (M_{VS}), for consumer-grade luminaires. The limits were set to $P_{st}^{LM} \leq 1$ and $M_{\mathrm{VS}} \leq 0.4$ ($M_{\mathrm{VS}} \leq 0.9$ until September 2024), where $M_{\mathrm{VS}} = 1$ and $P_{st}^{LM} = 1$ are the 50 % thresholds for the visibility of the TLA for average observer. When the value is less than 1, the phenomena are visible to less than half of the people.

We aim to study the TLA performance of the consumer-grade luminaires before and after the Ecodesign regulation was enforced. In addition, we aim to address the reliability of TLM measurements, especially derivation of the numerical values of TLA metrics from the raw measurement data.

2. Methods

The LED lamps were measured with a validated measurement setup, based on an integrating sphere. In total, we measured 80 different E27-based LED lamps from multiple manufacturers for P_{st}^{LM} and M_{VS}. We had 60 types of old lamps purchased prior to the EU Ecodesign regulation. The rest of the lamps were purchased in December 2021. The nominal luminous flux values ranged from 150 lm to 2452 lm for the old lamps, while their nominal power values were between 1 W and 20 W. Similarly for the new lamps, the nominal luminous flux values were between 30 lm and 1521 lm, and their nominal power values were between 0.6 W and 14 W.

All lamps were driven as specified by the manufacturer using an AC power source, while monitoring the voltage and current with a power analyzer. The TLM data were measured with a photometer and then digitized and stored via an oscilloscope for analysis by dedicated TLA software. The P_{st}^{LM} and M_{VS} values were calculated from data using two different MATLAB-implementations of the flickermeter and stroboscopic visibility meter. The first digital implementation was recommended by the IEC and the second independently developed by us. Defined test waveforms were used to study the performance of the meters before using them for analysis of real measurement data.

By using the data from the power analyzer, we were able to divide the lamps into four different LED driver topologies A-D. Type A lamps uses a full-wave rectifier with a smoothing capacitor and a DC-DC converter circuit at the output, type B lamps have a capacitive dropper circuit, type C lamps have a linear constant current regulator straight circuit, and type D lamps have switch-mode driver circuits. These lamp types produce distinct input current waveform, which can be seen from the power analyzer.

3. Results

Significant differences were found in the two digital implementations of the TLA meters when using the defined test waveforms. Our own flickermeter implementation decreased the deviations from the target values by an order of magnitude, on average, as compared with the IEC recommended flickermeter. In the M_{VS} meter implementation, our implementation

decreased the average deviation from the target values by almost two orders of magnitude when comparing to the IEC recommended M_{VS} meter. However, for both digital implementations the errors were sufficiently small to be used in the further studies of real LED lamps.

We found all four lamp types within the 80 lamps measured. The old lamps contained types A, B, and D, with 42, 4, and 14 lamps, respectively, while in the group of new lamps, only types A and C were found, with 18 and 2 pieces, respectively. We observed that the driver topology significantly affected the TLA behavior of the lamp. The P_{st}^{LM} value was less than 0.30 for all 80 lamps, which is significantly smaller than the Ecodesign regulation limit of 1. Type A lamps exhibited the best P_{st}^{LM} behavior among the different driver topologies, with an average P_{st}^{LM} value of 0.03, while types B, C, and D had average values of around 0.1.

The driver topology had more significant effect on the M_{VS} values. Type A lamps demonstrated the best M_{VS} behavior, as most of the lamps had practically zero M_{VS}. Only one Type A lamp from the older lamp group had higher M_{VS} value than the Ecodesign regulation's limit of 0.4. However, on average, type B lamps had M_{VS} values > 0.4 and type D lamps had M_{VS} > 1. In the group of new lamps, one type C lamp had M_{VS} < 0.4 and the other M_{VS} > 0.4, making it the only lamp type produced after the regulation has been enforced, that fails to comply with it.

We observed similar results with both digital implementations of TLA meters for most LED lamps. The largest deviations in the numerical values were 0.01 (P_{st}^{LM}) and 0.07 (M_{VS}). Such small differences do not affect the above considerations on the influence of lamp driver types.

Other uncertainty sources in TLA measurements were also considered, such as noise and nonlinearity of the photometer. Especially at low signal levels the contribution of noise in the measurement uncertainty is larger than that of the photometer nonlinearity and of our own digital implementation.

4. Conclusions

In conclusion, this study showed that luminaire manufacturers in EU seem to have started to favor the type A lamp topology in the manufacturing process when comparing the TLA results from the older and new lamp groups. As type A lamps produce smaller P_{st}^{LM} and M_{VS} values compared to other driver types, it complies with the limits set by the EU Ecodesign regulation. The manufacturers have also stopped using B and D type lamp drivers which has improved the overall TLA behavior on the market. The TLM measurement uncertainties of real LED lamps are sufficiently small to confirm the conclusion that the TLA performance of commercial LED lamps has improved due to the Ecodesign regulation.

PP19

VALIDATION OF A MICRO-REFLECTOMETER FOR ACCURATE CHARACTERIZATION OF THIN FILM COATINGS

Rastgou, M.[1], Danilenko, A.[1], Manoocheri, F.[1], Ikonen, E.[1,2]
[1] Metrology Research Institute, Aalto University, FINLAND, [2] VTT MIKES, VTT Technical Research Centre of Finland Ltd, FINLAND
masoud.rastgou@aalto.fi

Abstract

1. Motivation, specific objective

Accurate characterization of thin film structures is essential for developing modern electronic and photonic devices. Optical reflectometry is widely used to measure the optical properties of such structures non-destructively. However, reflectometers with larger beam sizes face limitations when characterizing small feature sizes. To address this limitation, we introduce our micro-reflectometer with a 150 µm beam diameter, which can accurately characterize micrometer-scale structures. Our specific objective is to validate the accuracy and reliability of the micro-reflectometer for thin film measurements by comparing its reflectance spectra to those obtained from a traceable spectrophotometer equipped with a goniometer accessory.

2. Methods

Validating the accuracy of the micro-reflectometer measurement requires understanding of the geometrical properties of its optics. The microscope objective in the micro-reflectometer defines the 150 µm beam focused on the sample. The illuminated cone of 22° half angle on the sample consists of a range of incident angles, determined by the numerical aperture of the microscope objective. Rays in the incident angles introduced on one half of the cone are collected in the other half. Based on this geometry, the resulting reflectance curve obtained from the micro-reflectometer represents the average of reflectance curves within this half-cone of incident angles. In contrast, the reflectance in a conventional spectrophotometer is measured at a fixed angle of incidence, which can be varied.

To validate the accuracy of the micro-reflectometer measurements, we compared the reflectance spectra of a selection of SiO_2 films on Si substrate measured by the micro-reflectometer to those obtained by our spectrophotometer. We performed the measurement at a range of fixed incident angles on the spectrophotometer to determine the effective angle of incidence for the micro-reflectometer. The comparison was done by comparing the reflectance spectra of both devices. We found out that there is a unique angle of incidence in the spectrophotometer measurements, where the reflectance spectrum agrees with that of the micro-reflectometer. That angle corresponds to the effective angle of incidence in the micro-reflectometer.

The optical properties of the samples can be analyzed by fitting a calculated reflectance curve to the measured data. The micro-reflectometer is equipped with software capable of fitting the reflectance curve by defined layer models from a wide library of materials. The fitting process of the micro-reflectometer's software is validated against a dedicated MATLAB code for calculating the reflectance from a thin-layer structure. A critical step in the validation of the software is to ensure that the average of the reflectance curves within a certain range of incidence angles matches the reflectance curve at the effective angle of incidence used for spectrophotometer measurements.

3. Results

We obtained the effective incident angle of our micro-reflectometer by comparing the reflectance curves of the measured samples with those obtained from our spectrophotometer at a range of incident angles. The microscope objective defined the range from 0° to 22° as the incident angles of the micro-reflectometer. The spectrophotometer measurements were made at the same angular range.

The effective incident angle for the micro-reflectometer was determined to be 11°, where the reflectance curves from both the micro-reflectometer and the spectrophotometer matched.

We then used the obtained effective incident angle in the fitting process to determine the thickness of the tested SiO_2 layers. The results showed good agreement with the nominal thicknesses and those obtained from fitting reflectance curves of both the spectrophotometer and micro-reflectometer. As an example, when measuring a sample with a nominal SiO_2 thickness of 500 nm, both the micro-reflectometer and spectrophotometer yielded the thickness of 508 nm through the fitting process. These results validate the accuracy and reliability of the micro-reflectometer measurements.

4. Conclusions

In conclusion, we introduce a micro-reflectometer with a 150 μm beam diameter that can accurately characterize micrometer-scale structures. Our objective was to validate its accuracy and reliability for thin film measurements by comparing its reflectance spectra to those obtained from a traceable spectrophotometer equipped with a goniometer accessory. During the validation process, we determined the effective incident angle of the micro-reflectometer to be 11° and utilized it to obtain the thicknesses of SiO_2 layers through the fitting process. The fitting results show a high degree of agreement between thicknesses obtained from the reflectance curves of the spectrophotometer and micro-reflectometer.

Our results demonstrate that the micro-reflectometer is a suitable tool for characterizing thin films, offering traceable thin film metrology. Moreover, the micro-reflectometer's high spatial resolution and scanning capability make it capable of characterizing complex thin film structures with small feature sizes.

POSTER PRESENTATIONS

Monday, September 18, 16:05-17:35

Poster Session 1

Monday, September 18, 16:05-17:35

PO02

THE EFFECT OF VARIOUS LED LIGHT HUES AND COLOR SATURATION ON STRESS MITIGATION FOR OFFICE WORKERS: AN EXPERIMENTAL STUDY

Asarasri, S.[1], Suprabha,Y.[2], Ounjai, K.[2,3] Bstieler, C.[1,4]
[1] School of architecture and design, King's Mongkut University of Technology Thonburi, Bangkok, THAILAND, [2] Biological Engineering Program, King's Mongkut University of Technology Thonburi, Bangkok, THAILAND, [3] Neuroscience Center for Research and Innovation, King's Mongkut University of Technology Thonburi, Bangkok, THAILAND, [4]Lighting Research and Innovation Centre, King's Mongkut University of Technology Thonburi, Bangkok, THAILAND
suphatsara.a@mail.kmutt.ac.th

Abstract

1. Motivation, specific objective

Globally, office workers often face high-stress levels for many reasons, adversely affecting their work performance, health, and well-being. Any tools to alleviate employee stress are valuable for their quality of life and the organization. With the broader adoption of LED technology, colored lighting has attracted more attention from design professionals and researchers as a means to reduce stress.

Several studies found that exposure to specific light colors can significantly impact mood and stress levels. Blue light, in particular, seems to have a calming effect and reduce feelings of anxiety and stress—similarly, green light links with the feeling of calmness and Relaxation. However, it is unclear which hue is more effective for stress reduction. Research on colour and emotions suggests that saturation is another essential characteristic, but lighting studies on the effect of saturation are still limited. Therefore, a better understanding of the effects of hue and saturation of blue and green light could guide a more time-appropriate and healthier colour lighting application.

This study investigates the effectiveness of colour lighting with different hues (blue and green) and their interaction with two saturation levels (high and low) in mitigating stress for office workers by comparing them to the neutral white light commonly used in the workplace. As hybrid work has become more common and many employees can work on-site or remotely, the results can provide lighting guides for relaxing spaces in the workplace and in a broader context.

2. Methods

This experimental study employed a full-scaled colour laboratory using a dedicated space at the university in Bangkok. The test room has no external window and negligible effects of daylight. Light sources are RGBW, and Amber LED strips with opal diffuser covers, providing indirect and uniform lighting on the room surfaces. The control system was linked to the computer, where the test conditions could be pre-programmed and retrieved. A cool white light illuminated the test room during the stress-induced session. Five lighting scenes - four blue and green colour lighting in low and high saturation and neutral white lighting - were on in random orders during the relaxing periods.

Fifty volunteers, 32 female (age 28.5 avg +/- S.D.3.75) and 18 male (age 28.7 avg +/- S.D. 3.69), participated in the study. They were all office workers from Bangkok. Before the experiment, the researcher performed the color-blind test using the Ishihara Test. Galvanic Skin Response (GSR) and heart rate (HR) sensors were placed on participants' index and middle fingers throughout the experiment to monitor their stress levels. GSR and HR were sampled at 60 Hz.

Each trial consisted of two parts – Stress inducing and Relaxation, each taking 190 seconds with 30 seconds of inter-trial interval. During the Stress-inducing part, participants performed an n-back task to induce stress by overloading the working memory. Afterward, participants were asked to rest under one of the five pre-set ambient lighting scenes. Five ambient light scenes were – 1. High saturated blue light (100%), 2. Low saturated blue light (50%), 3. Neutral white light, 4. High saturated green light (100%), and 5. Low saturated green light (50%). All these ambient light scenes were achieved by placing LED striplights (RGBW) 19.2W/m along the cove on the wall. In order to provide the same luminance perception as white light, the luminance of each coloured light had been set equal to white light luminance multiplied by applying the specific multiplier for each colour light; 40% is applied for Blue light (464 nm) and 50% for Green light (516 nm). Then the whole procedure was repeated but changed the ambient light scene during the Relaxation until completed all five scenes. Participants were separated into two groups to counter-balance the occurrence order of the pre-set lighting scenes.

In addition to the GSR and HR monitoring, participants were asked to evaluate their relaxation level on a scale of 1 to 5 before and after the exposure to coloured light. Moreover, after completing all five scenes, participants rated their preference for the most and least relaxing scenes. This interview and preference rating were to cross-analysis whether GSR/HR data and self-assessment results were consistent.

3. Results

The results indicated that both hues and saturation of colour lighting impacted stress recovery differently. The GSR analysis under five lighting scenes suggested that blue seemed slightly more effective in mitigating stress than green. Moreover, light colour saturation appeared to have a more substantial effect between these two hues. The blue and low saturation interaction reduced stress better than other lighting scenes. The bio-data (GSR) results also aligned with the self-assessed stress levels and selection of the most and least relaxing lighting scenes.

4. Conclusions

While previous research mainly focuses on the impact of lighting colour hue, this study highlights the importance of saturation levels and their interaction with hues on stress mitigation. Low-saturated lighting, particularly in blue, appears more effective. Further analysis and comparison of stress levels under the four colour lighting scenes and the neutral white light could provide better insight into the best lighting scenes for stress mitigation, health, and well-being. Future studies should also explore the effects of gender and age of the participant.

PO24

EVALUATING THE COLOR PREFERENCE OF LIGHTING USING DISPLAY SIMULATION: A VALIDATION WITH REAL SCENE OBSERVATION DATA

Wu, X.[1], Duan, J.[2,3], Deng, X.[1], Hou, Z.[1], **Liu, Q** [1*]
[1] Research Centre of Graphic Communication, Printing and Packaging, Wuhan University, Wuhan, CHINA, [2] School of Management, University of Science and Technology of China, Hefei, CHINA, [3] Zhejiang Jiaxing Digital City Laboratory Company Limited, Jiaxing, CHINA
liuqiang@whu.edu.cn

Abstract

1. Motivation, specific objective

The color preference assessment of light source is usually carried out in the form of psychophysical experiments, in which subjects were asked to evaluate the color appearance of specific objects under various light sources. The illuminated scenes can be built in a real environment with touchable objects or on a display with simulated images. However, due to the influence of light source measurement, image calculation, and observation mode during the simulation, the extent to which the simulation is close to the reality, i.e., the consistency of visual evaluation between the two, is an issue worth exploring. The consistency issue exists as long as a visual experiment involves displays, regardless of the purpose and methods of the experiment. In this study, the consistency of visual experiments with the purpose of evaluating color preference of light sources has been preliminarily explored.

2. Methods

To ensure the complete recording of color information and avoid problems such as metamerism and color appearance analysis difficulties, spectral reconstruction technique based on a commercial trichromatic digital camera and local weighted linear regression spectral estimation algorithm was used in this study to obtain the spectral reflectance of visual objects, which is combined with the spectral power distribution to calculate the experimental images.

Image color reproduction was carried out to evoke the colors in the reconstructed spectral images. Each pixel of the spectral image containing reflectance information is a calculation unit for image color reproduction. The spectral reflectance is multiplied by the spectral power distribution of the illuminants and the CIE 1964 color matching function for integration to obtain the three stimulus values XYZ. After the display calibration, a lookup table (LUT) constructed based on the gain-offset-gamma (GOG) model is used for the mapping from XYZ values to the RGB values of the final output images.

As a typical visual experiment object common in life, a plate of fruits was selected for simulation, while the experiment data of real scenes, which have been reported in one of our former publications, were used as a control. Six experimental light sources were adjusted to a low constant correlated color temperature (CCT) of approximately 3000K, while the Duv values ranged from -0.015 to 0.010 with 0.005 intervals (the Duv value provides information on the distance and direction of a color shift from the Planckian locus on the CIE 1960 u, v chromaticity diagram). On a calibrated display, participants evaluated the illuminated fruits and the light booth in which the fruits were placed, under the experimental light sources by a seven-point rating method.

3. Results

Overall, as Duv decreased, the average ratings of the four situations (two types of experimental objects in real and simulated situations) showed a consistent upward trend until Duv reached -0.015 when different degrees of ratings declines occurred. The consistency and variability are also reflected in the correlation coefficients. After excluding the evaluation under the light source with Duv = -0.015, the correlation and significance levels between the

simulated and real experiments were improved, especially for the empty light box (Pearson r from 0.693 to 0.984 and P value from 0.127 to 0.002 for empty light booth, Pearson r from 0.901 to 0.957 and P value from 0.014 to 0.011 for fruits), indicating possible differences in the observation patterns of the two objects in the simulated and real cases, as well as the unique effect of the light source on the visual evaluation at Duv = -0.015.

4. Conclusions

This study experimentally compared the visual evaluation of real and simulated scenes based on specific objects. The consistency varied in terms of the lighting conditions and perceived objects of visual scenes. During the color appearance analysis, color appearance shifts from real to simulated visual scenes were specifically found to be differences in hue angles, which were essentially caused by inconsistencies in color adaptation between the two psychophysical experiments. Meanwhile, the background color of the interactive interface on the display and the memory color of the fruits showed certain influence on the visual evaluation in terms of the perceived white point of the display and the color perception, respectively. These factors should be taken into account when evaluating images on display to maintain the visual consistency with reality.

PO27

TEMPORAL LIGHT MODULATION (“FLICKER”): A SET OF WAVEFORM AND METRIC TARGETS FOR INDUSTRY DISCUSSION

Miller, N.J.
Pacific Northwest National Laboratory, Portland OR, USA
Naomi.miller@PNNL.gov

Abstract

1. Motivation, specific objective

Temporal Light Modulation (TLM) is an increasing phenomenon in indoor, outdoor, and vehicular applications, due to the widespread adoption of LED sources. Less than half of LED lighting systems produce problematic TLM, but it is common in small-profile linear luminaires, decorative fixtures, residential luminaires, screwbase LED retrofit lamps, holiday light strings, vehicular tail lights, daytime running lights, dashboard displays, and even headlights. Unfortunately, there has been a delayed recognition that certain TLM waveform characteristics and viewing conditions can result in distraction and disorientation, cognitive effects, and serious health consequences in some populations. The neurological impacts may occur with or without conscious visibility of the TLM.

Although there have been significant efforts to quantify the visibility of the three visual responses to TLM, there are concerns. For example, P_{st}^{LM} as a metric for Direct Flicker (3 to 80 Hz) has been documented to exhibit varying values depending on sampling rate, windowing, and other calculation approaches. The Stroboscopic Visibility Measure (SVM) is very stable but may overpredict the visibility at frequencies at or above 500 Hz, and there is still no agreement on a phantom array effect sensitivity curve or metric. Furthermore, the phantom array effect has been shown to be visible under some conditions up to 11,000 Hz or higher.

Research into responses to TLM is underway, but guidance is needed now, since anecdotal evidence suggests a link to migraines, nausea and disorientation, and even more serious health consequences. Until there is more evidence, we need provisional guidelines to raise awareness among dimmer, driver, and luminaire manufacturers. The motivation behind this paper is to present TLM waveform guidelines and target values for international discussion.

2. Methods

A table is presented based on three levels of protection: Good (for general populations including migraineurs which make up 20-25% of the population), Better (for very sensitive populations who require more specialized environments), and Best (likely adequate for all populations). Target values are based on results from recent research into visibility of waveforms at frequencies above 90 Hz; and for lower frequency waveforms, recent technical papers documenting stability of direct flicker metrics. Waveforms recommended for very sensitive populations are limited to sinusoidal waveshapes, except when frequency >25,000 Hz. (This value is based on experience with electronically ballasted fluorescent systems that seems to have mitigated complaints of fluorescent flicker.) Target values are divided into categories according to frequency, and include duty cycle, modulation depth, and waveshape.

3. Results

This table is conservative, in the interest of reducing health impacts. It is frustrating to communicate the importance of limits on waveforms, since a large segment of the population does not visually perceive TLM, or if an individual does see it, they suffer no apparent ill effects. Thus, convincing some groups to change electronics designs is an uphill battle because they see no value in the inevitable tradeoffs among TLM responses, product cost, audible noise, and electronic interference.

4. Conclusions

The guidelines presented in this paper are not a faît accompli. They are a starting point for recommending wise and practical limits on TLM characteristics. Lighting industry input is needed, as is input from photometric laboratories, the neuroscience community, and light-and-health professionals.

PO28

INDIVIDUAL DIMENSIONS OF HUMAN-CENTERIC LIGHTING

Or, K. H.[1,2]
[1] Private Office of Ophthalmology, Istanbul, TURKEY, [2] Private Office of Ophthalmology, Hamburg, GERMANY
hilmi.or@gmail.com

1. Motivation, specific objective

Illumination (Human Centric Lighting) for humans aims to be compatible with human anatomy and physiology. Tissue and visual changes caused by diseases, pathological conditions and treatments can change the lighting requirements. When designing illumination for society and individuals, it is necessary to determine these perception defects in order to be able to make possible changes in light planning in advance.

2. Methods

In this screening study, diseases and pathologies that may be necessary in addition to lighting for the clinically normal are examined with their prevalence in the population. The best known ophthalmological and systemic diseases that can influence visual perception are examined with their known incidence in the world as well as the incidence and the degree of diseases.

3. Results

Diabetes mellitus, one of the diseases that can change the perception of seeing from the perspective of an individual illness with their different effects (cataract formation, macular edema, macular and peripheral retinal bleeding and exudate) most common observed diseases in adults in the world. If you consider that there is an incidence of 15% in the population, the extent of the individual differences in the perception of vision between humans can be determined. Different stages of each disease can cause a changed visual perception at any stage. In addition to eye diseases, the treatment of some eye diseases can also change visual perception. For example, panretinal laser treatments applied to the retina can change the perception of vision permanently. On the other hand, many diseases of the brain (although the eye is medically normal) can lead to visual disturbances.

4. Conclusions

The knowledge and consideration of the possible different needs of people who are not healthy in terms of light and visual perception in society can make human-centric lighting individual.

PO34

SIMPLIFYING THE COLOUR RENDERING INDEX

Sarti, B.[1], Plutino, A.[1], Armellin, L.[1], Rizzi, A.[1]
[1] Deparment of Computer Science, University of Milan, ITALY
beatrice.sarti@unimi.it

Abstract

1. Motivation, specific objective

The Ra (general colour rendering index), identify as the CIE Colour Rendering Index (CRI), is commonly used in standards and in the lighting industry for rating lights in terms of colour fidelity. However, several studies have shown limitations of the CRI, particularly since the wide diffusion of LED lighting, where the Ra values do not always match up with the users' visual evaluations. This discrepancy results from inaccuracies in the CRI's role as a colour fidelity index and perception-related colour quality aspects such as colour preference or colour discrimination. It is possible that assigning multiple roles to a single number could potentially create complexities, although this is out of the scope of this paper. Numerous attempts that try to rethink the color rendering index exist, but none of them is agreed as a valid replacement of the CRI.

In this work, we want to propose a simplification of the approach to color rendering. We aim at basing the approach only to the spectra of the illuminant under test, to check if the absence of a vision model can be acceptable to perform such a measure. The idea that forms the basis of this work is the assumption that a high-quality light source must have a good emission in all the wavelengths of the visible region, while deficits in the illuminant spectrum lower the chromatic rendering. For these reasons, we introduce the idea of this novel metric, called SDCRI (Spectral Divergence CRI), which simplifies CRI calculation.

2. Methods

Based on the above reasons, the mathematical definition of SDCRI is just a summation of the absolute value of the difference between the emission spectrum of the test light and a reference source. Different Spectral Power Distributions (SPD) are evaluated as reference illuminants, such as a flat spectrum, the D65, the SPD of phases of daylight or the SPD of a Plankin radiator having the same CCT of the test light.

To investigate if a lower divergence in spectrum energy across wavelengths corresponds to a better colour rendering of the light source, we evaluate the proposed metric in some perceptual experiments. First, we discuss two works from the literature, based on colour discrimination under different lights. Based on the number of users that fail to correctly order the patches under different test lights we calculate a rank of the lights tested in these studies and then correlate this rank with our metric and the R_a. Finally, in a similar way, we performed two experiments using the Farnsworth–Munsell 100 hue test in which 12 and 5 users with no colour deficiencies were respectively asked to correctly order all the patches under 8 different lights in total (4 sources for each experiment). In this case, the raking of the lights under analysis is calculated on the number of errors made by users.

3. Results

From the analysis of the results, R_a demonstrates to best correlate with the ranking of the lights tested in the two papers found in the literature, but also the SDCRI show a good correlation, even if lower, in all the computation with the different referent illuminants. On the contrary, in our experiments, R_a achieves the lowest results followed by the SDCRI computed with the SDP of the Plankian radiator as a reference, while the SDCRI computed with the D65 as reference illuminant has the highest correlation. Low correlations are also obtained by the SDCRI computed with the flat spectrum as reference SPD. The difference in the results between our experiments and the works found in the literature can be attributable to the presence of different LEDs in the set of testing lights.

4. Conclusions

In this study, we have investigated the relationship between the spectral distribution of lights and the results of colour perception experiments. Based on these preliminary results, our conclusion is that the proposed approach not only provides a simplification of the current methodologies to assess light colour rendering but also seems to correlate with the light source users' colour discrimination. Further studies that investigate other reference illuminants and a high number of tested lights are needed, also in order to perform fine-tuning of the metric.

PO40

BCD LUMINANCE ESTIMATION MODEL REFLECTING OPTICAL AND RECEPTIVE FIELD CHARACTERISTICS OF VISION

Takase, K.[1], Hara, N.[1]
[1] University of Kansai, Osaka, JAPAN
reckazuto@gmail.com

Abstract

1. Introduction

To achieve a comfortable visual environment in indoor spaces, architectural designers control the size, light distribution, and luminance of light sources. The control is based on the predicted value of the visual environment evaluation for the space, using the current glare evaluation indices such as UGR and DGP. These glare evaluation indices need to be used differently depending on the classification and characteristics of the applicable target. In recent years, a method for understanding the luminance distribution of a space from image data and predicting the visual environment evaluation using the luminance distribution is being established. However, there is a limitation in applying these glare evaluation indices to the method of evaluation prediction using images. In addition, although those indices imply the relationship between physical conditions and visual environment evaluation based on experiments during development, but the mechanism is a dark box. Originally, there exist various visual characteristics of the visual system between the lighting environment and the evaluation of visual environment, and these characteristics should be reflected in the estimation of visual environment. Recently, a glare evaluation model that includes various visual characteristics from the optical system to the nervous system has been proposed, but the model is not easy to use because its structure is very complicated. The problem is that there is insufficient consideration of whether the encompassed visual characteristics are suitable for the discomfort glare evaluation.

This study aims to develop a model that reflects the visual characteristics obtained in the discomfort glare evaluation experiment and consists only of sufficient factors to predict discomfort glare. The development of the model will lead to the establishment of a generic discomfort glare evaluation system.

In this paper, we propose a BCD luminance estimation model reflecting visual characteristics that can explain the interrelationship between variables that background luminance, light source luminance, solid angle, and position and glare evaluation obtained in the previously reported experiments.

2. BCD luminance estimation method reflecting light scattering, receptive field density, and receptive field sensitivity

Incident light in the eye is affected by optical scattering by the cornea and lens. Therefore, even if the difference in luminance at the boundary between the background and the light source is clear, the retinal illuminance corresponding to that boundary is unclear. Light scattering in the eye depends on the angle of incidence of the incoming light ray and the effect of scattering is known to increase from central to peripheral vision. Receptive fields linked to photoreceptor cells are existed in the retina. Receptive fields are thought to contribute to spatial resolution and has been studied in relation to the luminance difference threshold in the field of visibility. Receptive fields linked to photoreceptor cells are existed in the retina. Receptive fields are thought to contribute to spatial resolution and has been studied in relation to the luminance difference threshold in the field of visibility. Since the luminance difference threshold depends on the background luminance, the receptive field has sensitivity characteristics depending on the adaptation state. In addition, the receptive field is known to have spatial density characteristics that depend on the distribution of photoreceptor density, which is higher in central vision and lower in peripheral vision.

This study assumes that glare evaluation depends on the amount of light flux incident on a single receptive field and proposes a model for predicting discomfort glare that reflects the light scattering, the receptive field density, and the receptive field sensitivity as visual characteristics.

The model derives retinal illuminance by reflecting the light scattering on the luminance distribution consisting of background and light source corresponding to the visual field. The incident luminous flux in receptive field is derived by integrated the retinal illuminance with the solid angle of receptive field. The model judged to be discomfort glare, when the incident luminous flux in receptive field exceeds it to BCD, which is the basic criterion for judging discomfort glare.

PO47

DYNAMIC LIGHTING CONTROL FOR ENERGY SAVINGS BASED ON JUST NOTICEABLE DIFFERENCE EXPERIMENT FOR MUSEUMS AND RETAIL

Araiza, D.V.
University of California, Davis. Davis, UNITED STATES OF AMERICA
dvaraizasoto@ucdavis.edu

Motivation.

The U.S. Department of Energy estimates that commercial buildings in the U.S. account for 18% of total U.S. energy consumption, leading to energy expenditures worth $190 billion each year. Part of the commercial buildings which are accountable for considerable energy consumption, both retail stores and museums have visitors who occupy the spaces only for short periods of time. Additionally, artwork exhibited in museums is exposed to light for long periods, potentially compromising the durability of objects on display and contributing to the degradation of materials.

This presents an opportunity to conduct research into more effective and energy-efficient ways of lighting museums and retail facilities, such as dynamic lighting controls that adjust the lights during periods of vacancy, thereby maximizing energy savings. Nevertheless, some commercial buildings, such as museums and retail outlets, do not accept dynamic dimming due to potential visual disruption or distraction. As a result, dynamic dimming is not widely accepted in general practice. As part of conventional lighting protocols for energy savings, light levels are dimmed via occupancy sensors, but in a way that is perceptible to the audience, which decreases the light immediately.

To avoid any distractions in actual scenarios, this research explores the possibility of decreasing the brightness of the lights slightly so that the eye will not be able to perceive them.This research seeks to identify possibilities where dimming lights are not noticeable to the eye through a full-scale human subject study based on Just noticeable Different (JND). Based on a controlled study, this research explains the worst-case scenario where the audience looks for changes in light levels. In the real world, they will not be looking for a change. As a result of this research, a design protocol for dynamic lighting controls will be developed that may be employed in lighting museum exhibits and retail environments to contribute to energy savings.

This study investigates the JND of the human eye when dynamic lighting controls gradually decrease light levels. The study attempts to find an optimum lighting control protocol for dimming and ramp rates. Additionally, a new dynamic lighting protocol for museums can contribute to the art being lit at lower light levels than what is recommended by the IES guidelines when the space is vacant, maximizing the lifetime of works of art. A series of conclusions and recommendations about how lights can be dimmed in different ramping functions within short periods without human perception, can contribute to energy savings for retail and museums is explained as the outcome of this research.

Methods

A full-scale human subject study based on JND was conducted as part of this research, where different ramping conditions of light levels were tested and compared. This experiment used two different set-ups testing the central and peripheral vision to explain how we perceive changes in light levels and how we could perceive them applied to museums and galleries.

Participants were exposed to a controlled environment focusing all the light into one specific spot, for the first part of the experiment 5 sections were tested. In the first section lights changed instantly reducing 5%, 10%, 15%, 20%, 25% and 30% of illuminance levels. For the second section lights went to the same amount of illumination but a slow ramp of 5 seconds. The third section of the experiment lights went to the same amount of illumination but with a ramp of 10 seconds and for the fourth section the ramp was of 20 seconds. All with the purpose of comparing how reducing light with ramping rates can decrease human perception.

Results

Dimming ramping reduced significantly human perception for this experiment. When comparing changing light levels from 100 to 90, without a ramp is 70% detectable by subjects, in contrast to only 15% with ramping rates, whether 5, 10 or 20 seconds.

When changing light levels from 100 to 85 percent, there is not much difference in comparison to going up to 90 percent, and it is reasonably similar until lights change 20% going to 80, where 5 seconds ramp is detected almost for 30% of the participants. Between ramps of 5 seconds and 20 seconds, there is a difference in perception of about 20%, which shows that increasing the ramp period can contribute to reducing detection.

Ramping light levels from 100 to 75 was perceptible to participants in the three different ramps, ranging from 60% detection with a ramp of 10 seconds to 30% of detection with 20 seconds ramp. The most detectable ramp for 70% of illuminance was 5 seconds with 70% of perception.

When reducing illuminance levels, ramping rates can increment audience tolerance, being barely perceptible and even dimming 20% of total output. This reduction in detection brings the opportunity to be applied for museums, reducing light levels up to 80% light levels with a 20 seconds ramp shortly after visitors leave the space with occupancy sensors contributing to energy savings without audience detection.

Conclusion

Concluding the two parts of this experiment.It has been demonstrated that dimming lights with a ramping rate can significantly reduce human perception in comparison to dimming lights without a ramping rate. Dimming light levels 20% with any of the ramping rates tested in this experiment makes a huge impact, reducing perception from the participants, with only 25% of perception, with can be applied to the real world, considering that in this experiment, participants were expecting a change in light levels, which could represent less perception in a museum or retail environment.

Dimming lights with a ramping rate of 5, 10 and 15 seconds, resulted in similar perception percentage, when the change was minimal, less than 15% of illuminance levels. Peripheral vision testing resulted in less experimental uncertainty, with fewer participants ensuring perceiving a change in light levels. 10 Seconds Ramp is very effective to reduce human perception with on axis and of axis experiment to any of the percentage of changes tested in this experiment.

PO74

EVALUATION OF EMOTIONS INDUCED BY BIOPHILIC LIGHTING PATTERNS USING EEG AND QUALITATIVE METHODS

Hill, A.J., Triantafyllidis, G.A.
Lighting Design Lab, University of Aalborg, Copenhagen, Denmark
gt@create.aau.dk

Abstract

1. Motivation, specific objective

This pilot study examines how lighting can support people's well-being in urban environments by designing lighting projections using biophilic principles and conducting a mixed-method assessment.

Every year more people are living in urban environments with as much as 75% of Europeans living in developed areas in 2020. Urban living offers many benefits to people however, it also comes with health risks. Living in the city has been associated with increased mental health risks including stress, anxiety and mood disorders. Biophilic principles offer an approach for helping to relax people by incorporating natural, organic elements into designs and spaces. The immediate idea that comes to mind is to add green spaces to cities. However, the capacity to increase natural parks and landscapes to existing urban environments is very limited and access to land is highly competitive.

Perhaps lighting design can offer support, considering green spaces and nature in a less literal but more immediately achievable way – through analogues of nature. Using lighting patterns inspired by the natural environment to light urban spaces because, as biophilic principles suggest, these analogues should also generate positive mood effects. These could be applied with a focus on enhancing existing city environments and connecting people to nature for their well-being.

Previously, traditional research relied on self-report techniques to assess emotions of participants. Now, electroencephalography (EEG), which captures and analyses the electrical activity of the brain, is gaining recognition as a reliable method for evaluating emotional states of individuals.

In this context, this work uses EEG along with qualitative testing to understand if combining biophilic design principles and electric lighting could increase peoples' connection to nature in the urban environment, generating positive emotions of relaxation to support well-being in the community.

2. Methods

The following two hypotheses were tested:

- Biophilic light projections will generate more positive emotions including relaxation than non-biophilic light projections.
- Patterned light will be more positive and calming than standard non-patterned light.

The test was a mixed method using EEG for quantitative data and an adapted Discrete Emotions Questionnaire (DEQ) for qualitative data with five participants.

2.1 EEG Equipment and Software

The Unicorn Black EEG headset with 8 channels was used for testing participants with the band power software package.

2.2 Discrete Emotions Questionnaire

The whole DEQ covers a range of emotions, and four emotions (calm, anxious, relaxed and worried) were selected for the questionnaire. These four emotions could be organised into two groups: anxious (anxious and worried) or relaxed (calm and relaxed). A rating scale of 1-7 was provided for each pattern and emotion where 1 represented ‘not at all’ and 7 represented ‘an extreme amount’.

3. Results

Four biophilic patterns were designed using local ecology (Waves, Gum Leaves, Daffodil and Pines) and for comparison there were four non-biophilic patterns (Bricks, Lines, Circles and Roofs). These four non-biophilic patterns were inspired by urban city scapes such as “roofs” of buildings, “lines” of skyscrapers, “bricks” of buildings and “circles” representing paths around the city.

The results analysis used the valence and arousal model. The level of autonomic activation caused by an event is referred to as arousal, ranging from calm (low) to excited (high). Valence refers to the degree of pleasantness generated by an event, rated along a scale ranging from negative to positive.

Alpha waves were used to map the arousal levels (a reduction in alpha was considered an increase in arousal) and Gamma waves were understood to represent valence (a reduction in gamma can represent an increase in valence).

Overall, the EEG results showed that 75% of the biophilic patterns had a positive valence response as compared to the control with neutral to slightly positive arousal. 50% of the non-biophilic patterns showed an expected negative valence state representing a negative emotional response as compared to the control.

The qualitative survey demonstrated that the biophilic patterns had a 135% more positive result than the control and 417% more positive than non-biophilic patterns. The Gum Leaves pattern was the most preferred pattern in the survey with a 65% more positive result than the control followed by the Waves pattern with a 44% more positive than the control.

The method for analysing EEG data using the arousal and valence model appears to provide some indications that align with survey results. The Waves pattern was the most positive biophilic pattern from the EEG and rated as the second most positive from the qualitative survey. Additionally, the Waves pattern was rated by 40% of participants as their favourite pattern. Similarly, the Gum Leaves pattern was the second most positive biophilic pattern from the EEG results and rated the most positive pattern in the qualitative survey. There were also further indications relating the quantitative and qualitative data particularly in regard to specific questions (as opposed to ratings) such as ‘most favourite pattern’ and ‘least relaxing’.

4. Conclusions

Using EEG for testing lighting atmospheres and emotions has been applied before but testing biophilic design principles in electric lighting employing a mixed method using EEG and the valence arousal model is a novel approach. This work investigated biophilic lighting projection atmospheres and the analysis offered a way to consider the EEG data in the context of emotions from lighting.

From the literature review, there were no other identified lighting tests that considered analysing the EEG data in this way, using the valence arousal model with alpha and gamma waves. Given the fact that indications show some interesting relationships between the survey rankings, open questions, and EEG data, this could be a new way for lighting EEG testing data to be considered. It could also be further investigated in relation to using both alpha and beta low waves as the arousal measurement.

PO83

PERCEPTUAL COLOUR CHANGES IN HIGH-DYNAMIC-RANGE CONDITIONS: AN EXPERIMENT ON APPEARANCE MATCHING AND COMPARISON WITH CIECAM02

Baek, Y.S. [1], Hwang, J[1]. and Kwak, Y. [2]
[1] Photometry and Radiometry Group, KRISS, Daejeon, SOUTH KOREA, [2] Department of Biomedical Engineering, UNIST, Ulsan, SOUTH KOREA
yeseul.baek@kriss.re.kr

Abstract

1. Motivation, specific objective

The motivation of this study is to investigate how colour perception changes under high dynamic range (HDR) lighting conditions. The specific objective is to evaluate the colour changes using the colour matching method and to compare the results with the predictions of the CIECAM02 colour appearance model. The study aims to determine if human vision adapts to the different lighting environments, and if the CIECAM02 model can accurately predict colour appearance under different lighting conditions. The study also investigates the effect of luminance and chroma on colour perception and whether there is a meaningful hue shift in certain colour ranges. The ultimate goal of the study is to improve our understanding of how humans perceive colour under HDR lighting conditions, which could have important implications for fields such as lighting design, art, and visual perception research.

2. Methods

This study evaluated colour changes under HDR lighting conditions using the colour matching method. Two light booths with adjustable colour temperature and luminance were used, with one booth having bright luminance and the other having dim luminance. The correlated colour temperature was set to 6500K under all conditions.

The experiment was conducted for four lighting conditions based on luminance ratio. Conditions 1 and 2 had the same luminance ratio of 1:15, but Condition 1 was a very bright environment with luminance levels of 300 cd/m^2 and 4,500 cd/m^2, while Condition 2 was relatively dark compared to Condition 1 with luminance levels of 20 cd/m^2 and 300 cd/m^2. Condition 3 had a luminance ratio of 1:56, with luminance levels of 80 cd/m^2 and 4,500 cd/m^2. Condition 4 had a luminance ratio of 1:225, corresponding to the square of 1:15, with luminance levels set to 20 cd/m^2 and 4,500 cd/m^2.

The experiment used colour patches based on the NCS (Natural Colour System). The patches were varied in hue, lightness, and chroma for eight colour groups (R, G, B, Y, RB, BY, GY, and YR). The basic NCS colours often have a significant colour difference that makes them very easy to distinguish from other colours, so in experiments, additional colour patches were created to solve this problem. These patches are arranged in order according to the NCS system, helping participants in the experiment select colours that are similar to the reference sample through them. The arranged colour panels were placed in the light booth with bright lighting. The reference colour samples for each colour group were placed in the light booth with dim lighting.

A total of 12 participants with normal colour vision took part in the experiment. Each participant was asked which sample from the various samples of colour arrays in the bright booth looked most similar to the reference sample placed in the dim booth. They were allowed to freely alternate between the two booths and were encouraged to choose the most similar colour as much as possible.

3. Results

All measured patches in each lighting booth environment were calculated using CIECAM02 for lightness (J), chroma (M), and hue (h). In addition, CIECAM02 was used to predict the values of J, C, and h for each reference patch in the dark lighting booth that would be seen in the

bright lighting booth. In this study, these predicted values were compared to the JCh values of patches actually matched by the participants.

Regarding brightness, as we already know, the participants chose colour patches with relatively lower lightness levels in the bright environment because patches appear brighter. They matched darker patches as the luminance ratio between the two booths increased. This is similar to the well-known colour appearance phenomenon. When comparing J values in CIECAM02, if the subjects had adapted well to both lighting booth environments, the predicted J value and the matched J value should be the same. However, the matched results appeared darker than the predicted values, indicating that CIECAM02 does not fully explain the appearance of colours under different lighting conditions.

According to the existing theory, colourfulness is perceived as higher as the surrounding brightness increases. Therefore, in bright environments, participants should have selected patches with less chroma in order to match the colours, as they would have perceived the patches as being more colourful. the participants actually chose patches with higher chroma in the brighter environment, which goes against the existing theory.

Regarding colour, a meaningful hue shift was observed in the red colour range. Under high luminance lighting, the colour was shifted in a yellowish direction by one or two steps prior to the reference NCS colour. However, this tendency gradually decreased in environments with a large difference in luminance. This phenomenon was observed not only in red colours, but also in colours close to YR and RB. No distinct difference similar to red colour was observed in other colours.

4. Conclusions

If human vision adapts properly to each lighting environment, the predicted value and the selected value should match in CIECAM02. We assumed that the adaptation of the eye changes depending on the lighting situation when people observe the colour of an object under different lighting conditions. In other words, we assumed that local adaptation occurs and set the CIECAM02 input parameters accordingly. However, through this experiment, we confirmed that the predicted value and the selected value did not match in this situation. In the two booths where the difference between the two lightings was particularly large, such as condition 4, the participants seemed unable to adapt to either lighting. In fact, the participants answered that more time and effort were required for colour selection as the difference between the two lightings increased, indicating difficulty in local adaptation. To confirm this, we assumed global adaptation, where the eyes adapt to the brightest luminance of the two lightings, and compared them by changing the input parameters of CIECAM02. However, this also showed that the predicted value and the selected value did not match.

PO95

QUANTIFYING THE BRIGHTNESS OF CHROMATIC LIGHTING IN A WIDE FIELD OF VIEW

Durmus, D.[1]
[1] Pennsylvania State University, University Park, USA
alp@psu.edu

Abstract

1. Motivation

Architectural spaces often utilise polychromatic light sources that are nominally white, but specialised applications, such as hospitality, entertainment, theatre, and signage, might require the use of narrowband (chromatic) lighting. In such cases, lighting designers face challenges in specifying and designing chromatic light sources due to the photometric measures' (i.e. illuminance and luminance) poor performance of estimating brightness. Since photometric measures are based on the CIE 2-degree standard photometric observer that is derived from experiments of flicker perception (heterochromatic flicker photometry, critical flicker fusion) and edge detection (minimally distinct border), it is reasonable to assume that chromatic light brightness cannot be estimated using standardised photometric measures.

Past research studies investigated chromatic light brightness through a similar concept, the Helmholtz–Kohlrausch (H-K) effect – the change in brightness of perceived colour, produced by increasing the purity of a colour stimulus while keeping its luminance constant within the range of photopic vision. Researchers developed colour appearance models (CAMs) to estimate the H-K effect based on data from visual experiments with related and unrelated colours shown in displays and booths. However, these mathematical models are recommended only for narrow field of view. Since most architectural spaces are immersive environments seen in wide fields of view, there is a need to evaluate the performance of the existing metrics to estimate the brightness of chromatic lighting.

2. Methods

A visual experiment was conducted in a 4 m x 4 m x 2.7 m windowless room located inside a lighting laboratory. The walls were painted with neutral grey paint Munsell N8. The ceiling was covered with white tiles, and floor was dark grey carpet. Fourteen participants between the ages of 18 and 25 who have normal colour vision took part in the experiment. Participants sat inside the room (totally immersed) and were asked to judge the brightness of the room using the magnitude estimation method. In a sequential presentation, participants were first shown a reference white light (T_{cp} = 3874 K, D_{uv} = 0.0083, L_v = 10 cd/m^2, $E_{v,h}$ = 57.4 lx, $E_{e,h}$ = 0.166 W/m^2) for two minutes to allow full chromatic adaptation. Participants were told that the brightness of the room under the reference white light was 50. Eighteen test chromatic lighting conditions were generated by using three narrowband red (λ_{peak} = 610 nm), green (λ_{peak} = 525 nm), blue (λ_{peak} = 475 nm) LEDs, and their combinations (red + green, red + blue, green + blue) at three light levels. Light levels depended on the multi-primary LED system's ability to generate visible light, but they consisted of a lower level (e.g. L_v = 3 cd/m^2), a medium level (e.g. L_v = 10 cd/m^2), and a higher level (e.g. L_v = 15 cd/m^2). After the reference white light, a chromatic test light was shown for five seconds, and participants were asked to judge the brightness of the room relative to the reference white light which was 50. There was no upper limit for the brightness scale. After the test light, the reference white light was shown once again for 20 seconds to restore participants' chromatic adaptation and reduce memory effects. Each test lighting condition was shown once for five seconds with reference white light in between for 20 seconds.

3. Results

The performance of the metrics was evaluated against participants' subjective evaluations of brightness of chromatic stimuli. Results indicate that the brightness measure *Q* of CAM02-

UCS and CAM16 were poorly correlated with subjective brightness judgments (R^2 = 0.0002 and R^2 = 0.0014). On the other hand, the brightness measure Q for CAM15u (a CAM developed for unrelated self-luminous stimuli) was highly correlated with subjective brightness perception (R^2 = 0.6911). Photometric measures of horizontal illuminance ($E_{v,h}$) and luminance (L_v) were also highly correlated with subjective brightness judgments (R^2 = 0.7263 and R^2 = 0.7598). The highest performing metric was a brightness measure specifically developed for the H-K effect (Q_{HK}), which was developed by adjusting the CAM16 parameters (R^2 = 0.8338). It should be noted that the radiometric equivalent of illuminance (horizontal irradiance $E_{e,h}$) was also highly correlated with subjective brightness judgments (R^2 = 0.7228). This is most likely due to the limited number of intensity levels for the test lighting conditions, and the lack of non-visible radiation (infrared or ultraviolet) in the multi-primary LED system that was used to generate the stimuli. The limitations of the study include small sample size, younger participants, lack of repetitions of the stimuli, and limited luminance range for the test stimuli.

4. Conclusions

Architectural spaces are often illuminated with nominal white light sources, but chromatic lighting can play a vital part in specialised design applications. Anecdotal evidence from practicing light designers suggests that photometric measures cannot predict brightness of chromatic stimuli. In colour science literature, there are metrics developed to quantify the H-K effect for narrow field of view. It is reasonable to assume that these existing metrics can predict chromatic light brightness in wider field of view as well. Here, a psychophysical experiment was conducted to test the performance of existing metrics in estimating chromatic brightness. The results from the visual experiment suggests that the brightness of chromatic lighting can be estimated using CAM Q brightness measures that are specifically developed for the H-K effect, as well as photometric measures, such as luminance and illuminance. However, the high correlation between horizontal irradiance and subjective brightness judgments underline the limitations of the study.

Results from the study can also be beneficial to understand smart and integrated lighting systems that emit chromatic lighting for human circadian entrainment or plant growth. Future research should investigate the metric performance using a large number of stimuli, as well as light sources that contain radiation beyond visible spectrum. Other experimental settings, such as adjustment or 2-alternative forced-choice (2afc) methods in a side-by-side viewing condition, can also be utilised to evaluate the metric performances.

PO97

EVALUATION OF LIGHT DISTURBANCE SOURCES AND THEIR EFFECT ON HUMAN VISION

Dusek. D[1], Dupuis. P[2], Vik. M[1], Zissis. G.[2], Richter. A.[1]
[1] Technical University of Liberec, Liberec, CZECH REPUBLIC, [2] Paul Sabatier University, Toulouse, FRANCE
dominik.dusek@tul.cz

Abstract

1. Motivation, specific objective

There is now an increasing emphasis on reducing the overall level of lighting in towns and villages. This has an understandable impact not only on road safety but a whole range of other situations. The main objective of this research is to develop a specific analytical tool to characterize the average brightness levels generated by street public lighting. This analytical tool should be able to determine the difference in the perception of the adjacent scene for photopic and mesopic adaptive luminance. The purpose is to test whether, as a matter of economy, street lighting could be dimmed to provide a mesopic pedestrian vision regime while maintaining adequate safety. In addition, possible interference from bright sources such as advertising hoardings was tested: whether they could revert the vision mode to photopic, temporarily reducing visual gain and causing some problems with immediate perception. The transition area between the photopic and mesopic thresholds is important for drivers/pedestrians. The threshold between photopic and mesopic vision is set at 5 $cd.m^{-2}$ by the CIE. Here it is also important which colors switch vision more from photopic to mesopic vision. It is also necessary to consider how which colors are perceived with reduced adaptation time and how these colors affect/are affected at the level of the transition between photopic and mesopic brightness.

2. Methods

The following measuring instruments were used for each night measurement - a calibrated luminance camera - Canon EOS 50D, a Specbos 1201 spectroradiometer and a Konica-Minolta LS-100 luminance meter. The camera was on a tripod. The main idea was to prepare a brightness map of the whole scene. The selected scanning height was 1.7 m. To get the full range of luminance, we had to use the additional XHDR setting of the used brightness camera (Extra High Dynamic Range). We took several images with different exposure times (from 20 s to 1 ms). We used a fixed aperture (5.6) and ISO 400 sensitivity throughout. The software used was PhotoLux 3.1 and JETI.

The program for subsequent analysis was created in MATLAB using the Image Processing and Computer Vision toolbox as standalone GUI.

3. Results

Thanks to the special analysis tool we are capable to compare the data from both scenes. Globally, the visibility in the street with smart lighting system was adequate. The mesopic luminance map establishes that the whole field of view lies in the mesopic range, except for very few sources in the photopic range. Thanks to that we can prove, that pedestrian or driver of the car is in mesopic vision. This is much better because he can easily see the obstacles and he is not annoyed.

Our analysis showed that the second street with using an advertising panel is more disturbing for the pedestrian/driver. The vision will be changed from mesopic into photopic. The

pedestrian/driver is going to look in the way of shop window which leads to worse adaptation and visual task.

We also measured the luminance of luminaires and the shop windows. This area switches the vision into photopic. If he investigates the luminaire or into the shop windows of the mall, the vision is going to switch to the photopic vision for a few minutes. In this case the pedestrian will feel for a few minutes annoyed, uncomfortable and the visual task will be worse. The adaption time of the eye will get worse. Thanks to this measurement we can say, that using of over lighted advertising window is a wasting of energy and the light pollution is generally increased. The analysis tool makes it easier to identify areas that are potentially distracting for drivers/pedestrians.

Thanks to logarithmic function of the data, we can view the whole luminance in the 3 levels of the luminance – high, medium, and low. We can also detect a contrast ratio (for example pavement-motorway). Due to that we can describe a luminance contrast. Thanks to the tool we can tell, if the street is comfortable or no, annoying, safe, unsafe, with less consumption.

Generally, we can say, that this tool is going to be useful for the further photopic analysis of the whole scene. Thanks to this tool we are now able to see a disruptive element in the whole scene. In the future we are going to continue in this field of work. For easier control there has been added GUI.

4. Conclusions

The measurement showed us, that street with the smart lighting system can be useful for the pedestrian. On the other hand, the measurement from the center of town showed, that advertising panels are annoying and switch the vision into the photopic vision. This adaptation to the photopic vision can be disruptive for pedestrian and driver as well.

Due to that the pedestrian/driver is not able to clearly see obstacles for a few minutes. It would be good to reduce the brightness of billboards and advertising panels, which can save the money and improve the visual task of the driver/pedestrian. Thanks to our program we are capable to analyze whole scene and tell, which type of human vision was used. It has also been shown that different colors (e.g. on a mannequin's clothing) can change the visibility but also the type of vision of the pedestrian/driver. Based on research, it is also possible to tell, which colors can change the type of vision.

PO107

COLOUR VISION DEFICIENCIES IN THE DIGITAL TIME: A SURVEY OF USER EXPERIENCES WITH MODIFICATIONS TO AID THEIR COLOUR DISCRIMINATION

Hovis, J.K., Mazur, S.
School of Optometry and Vision Science, University of Waterloo, Waterloo, ON, CANADA
jhovis@uwaterloo.ca

Abstract

1. Introduction

Coloured digital displays are ubiquitous in everyday life, and the extensive use of colours could create problems for individuals with a colour vision deficiency. With the increased use of digital displays, there has been a renewed interest in finding solutions that would assist individuals with a colour vision defect to discriminate colours. As part of a survey of colour defective's experiences with digital displays, we asked whether they have tried any of these aids and whether they were effective.

2. Methods

An online survey was conducted in Canada and the United States, which asked about problems individuals with colour vision deficiencies experienced in using digital displays, along with possible aids they have tried. This paper will present the results from the aids portion of the survey.

The survey asked whether the respondents had tried cell phone apps that translate the colour from other displays, colour management apps included in various operating or gaming systems, colour alteration on a trial-and-error basis, changing to grayscale, use of coloured lenses, using larger monitors, or other possible solutions to help improve their colour discrimination when using digital displays.

3. Results

Three hundred eighty-one (101 females) responded to the survey. Of the 381 respondents, 64.8% (n=247; 77 female) of the respondents tried at least one aid. The respondents selected the following eight modifications: use cell phone apps for identifying colours (n=70, 28.3%); use colour contrast enhancing apps included in the operating or gaming system (n=107, 43.3%); trial and error adjustment (n=132, 53.4%); changing to grayscale (n=49, 19.8%); use coloured filters, tinted spectacles or contact lenses (n=47, 19.0%); purchased a larger monitor or used a SmartTV to display the image (n=45, 18.2%); avoid using the display (n=42, 17.0%); or other changes or modifications (n=2, 0.8%). Overall, females were slightly more likely to try a display enhancement than males, with 76.2% of the female respondents trying at least one of these alterations compared to 60.7% of the males.

For the most common aid of trial-and-error adjustments, the ranking of the effectiveness of this solution was 1.3% male and 2.9% female for “not at all”, 26.3% male and 34.3% female for “a little”, 51.3% male and 31.4% female for “some”, and 21.3% male and 31.4% female for “a lot”. The other aids had a similar rank order of the level of their effectiveness.

From the respondents who did mention using aids on their digital displays to assist them with colour-related judgments, the solutions were most commonly applied to desktops/laptops (68.4% - 72.4% male, 59.7% female); tablets (55.5% - 54.1% male, 58.4% female); cell phones (40.5% - 40.0% male, 41.6% female); touch screen digital whiteboard & whiteboard computers (15.8% - 13.5% male, 20.8% female); immersive systems (10.9% - 10.6% male, 11.7% female); automotive electronic display systems; (11.3% - 10.6% male, 13.0% female) and other digital displays (5.7% - 6.5% male, 3.9% female).

4. Conclusions

The study showed that most individuals with colour vision deficiencies tried some aid to help with their colour discrimination when using digital displays. The majority found the aids to be at least a little effective, with approximately 25% reporting that they helped a lot. The relatively high use of aids to help with colour discrimination may be attributed to the increased awareness of their availability and the ability to adjust the colour settings to their preference. The aids were most commonly used on desktops/laptops and cell phones. Likely, this resulted from these devices being more prevalent in people's daily lives. The result that only a minority of users found the aid to be highly effective suggests that more work is needed in designing software solutions that can enhance the experiences of these individuals to discriminate colours on digital displays.

PO114

SPECTRAL SENSITIVITY FUNCTION OF THE PHANTOM ARRAY EFFECT AT DIFFERENT WAVELENGTHS

Kang, H.[1], Lee, J.[1], Lee, C-S.[1]
[1] Yeungnam University, Gyeongsan, REP. OF KOREA

hye-ran@yu.ac.kr, chansu@ynu.ac.kr

Abstract

1. Motivation

The phantom array effect is a type of temporal light artefacts (TLA) caused by fluctuations in luminance or spectral distribution, resulting in perceived changes in the spatial position or shape of objects. Previous studies have shown that the visibility of the phantom array effect in different spectral distributions such as red, green, and blue is different. In this study, we would like to know how different wavelengths affect the visibility of the phantom array effect in various spectrum.

2. Methods

For this purpose, we made a new lighting source with ten peak wavelengths from violet at 420nm to far red at 730nm, including amber, cyan, and royal blue LEDs as well. We evaluate the threshold frequency of the phantom array effect in each narrow band LED that is controlled by PWM modulation up to 30 kHz. The weighted up-down method starting from 1 kHz is used for the evaluation of threshold frequencies.

3. Results

The experiment results show that the threshold frequency of the visibility of the phantom array effect depends on the peak spectral frequency of the light source. We also analyse the results according to the LMS cone sensitivity for each wavelength.

4. Conclusions

This paper presents a new spectral sensitivity function of the visibility of the phantom array effect. The presented spectral sensitivity function may need to be taken into account when developing visibility models of the phantom array effect.

PO122

USING MUNSELL SOIL COLOR CHARTS IN MARS AND EARTH

Melgosa, M.[1], Sánchez-Marañón, M.[2], González-Galindo, F. [3], Vicente-Retortillo, A.[4], Cuadros, J.[5]
[1]Department of Optics, University of Granada, Granada, SPAIN, [2]Department of Soil Science and Agricultural Chemistry, University of Granada, Granada, SPAIN, [3]Department of Solar System, Institute of Astrophysics of Andalucía (CSIC), Granada, SPAIN, [4]Astrobiology Center, INTA-CSIC, Madrid, SPAIN [5]Department of Earth Sciences, Natural History Museum, London, UNITED KINGDOM

Contact email address: mmelgosa@ugr.es

Abstract

1. Motivation, specific objective

The International Commission on Illumination (CIE) has standardized the spectral power distribution (SPD) of light on the surface of the Earth as a function of the selected correlated color temperature (CCT) in the range 4000-25000 K. This constitutes the so-called 'CIE daylight illuminants'. Similarly, from a reduced set of experimental irradiance measurements, SPDs of lights on the surface of Mars have been proposed for CCTs in a reduced range from 4600 K to 5400 K. Although the Earth and Mars receive sunlight, the SPDs of lights on the surfaces of these two planets are different, because of the different thicknesses and chemical compositions of their atmospheres, different surface dynamics (e.g. significant amounts of dust on the surface of Mars), etc. Accordingly, it can be expected that colors of specific objects on the surface of Mars and Earth will be not identical (color inconstancy), even in the case of irradiation by lights with the same CCT. Experts in soil science, geology and other fields may appreciate knowledge on the influence of the SPD of light in Mars on colors of materials, looking for accurate interpretations and analyses of current or future images obtained in Mars.

Traditionally, soil color charts offer an affordable way to classify, communicate and evaluate the color of soil samples. This paper deals with the problem of determination of soil colors by using the Munsell soil color charts, assuming that computed CIELAB color differences may be an acceptable approach to the best soil-chip visual match performed by the CIE 1964 standard observer. Specifically, our current goal is to test potential changes of the Munsell notation of a set of clay samples when they are illuminated by lights in Mars in place of lights in Earth.

2. Methods

We performed spectrophotometric measurements in the range 400-700 nm in steps of 10 nm for: 1) A set of 55 clay samples, which may be considered representative and analogous to those existing in Mars; 2) A set of 238 chips in a completely new issue of the Munsell soil color charts (hues 10R, 2.5YR, 5YR, 7.5YR, 10YR, 2.5Y and 5Y; the 'gley chips' were missed). We considered three normalized (Y_{10}=100) lights: D65 illuminant (the main CIE standard illuminant) and two lights in Mars, named M46 and M54 because they have CCTs of 4605 K and 5406 K, respectively. The M46 and M54 lights have extreme CCTs values, considering the available SPDs of light in Mars from some irradiance measurements on the surface of this planet. The CIE color fidelity indices (R_f) for M46 and M54 were very high (98.0 and 97.7, respectively), and both lights had chromaticities below the Planckian locus at the same distance (Δ_{uv}=-0.002).

Under each of the 3 mentioned lights (D65, M46 and M54), we look for the nearest Munsell chip to each of the 55 clay samples in CIELAB color space, assuming the CIE 1964 standard observer. Here we have not used CIEDE2000, the current CIE/ISO recommended color-difference formula, because in many cases we found color differences above 5.0 CIELAB units, the official upper limit for the use of CIEDE2000. Note that for the mentioned search we don't need a chromatic adaptation transform, because the clay samples and Munsell chips are under the same viewing conditions. However, for computation of color inconstancies of clay samples and their nearest Munsell chips when the light sources change, we used the chromatic adaptation transform model known as CIECAT16.

3. Results

Assuming the CIE 1964 standard observer, the average ± standard deviation values of CIELAB color differences between the 55 clay samples and their nearest Munsell chips were very similar for D65, M46 and M54: 3.8 ± 1.7, 3.8 ± 1.6 and 3.8 ± 1.7, respectively. Hue-differences were the main component (above 50%) of these CIELAB color differences. Considering as reference the Munsell notations of the 55 clay samples under D65 illuminant and CIE 1964 standard observer, the Munsell notation for the same standard observer changed for 10 samples (19%) under M46, and for 4 samples (7%) under M54. The smaller number of changes obtained under M54 may be attributed to the fact that that M54 and D65 have closer CCTs. All these changes (except one) in Munsell notations were in the same sense: Decrease (i.e. a more reddish hue) of one or two hue Munsell steps when the main light in the Earth (D65) is replaced by one of Mars lights considered (M46 or M54).

Current color specifications of clay samples using Munsell soil color charts imply metameric matches, in such a way that in our current case the change of the light source modified the colors of the clay samples and nearest Munsell chips in a very similar way. Specifically, using CIECAT16 (full adaptation degree D=1), the color inconstancies values (average ± standard deviation) when the D65 illuminant changed to M46 or M54 were very small: For the 55 clay samples, 0.8 ± 0.4 or 0.5 ± 0.2 CIELAB units, respectively; for nearest color chips to clay samples 1.0 ± 0.4 or 0.5 ± 0.2 CIELAB units, respectively.

4. Conclusions

For a set of 55 clay samples like the ones existing in Mars, the percentages of samples changing their Munsell notations was 19% and 7% for changes from D65 to M46 and from D65 to M54, respectively. Therefore, Munsell notations of most tested 55 clay samples remain unchanged (except perhaps 1-2 Munsell-hue steps in a few samples) under D65, M46 and M54. Assuming a full adaptation degree and the CIECAT16 model, color inconstancies for the 55 clay samples and their nearest Munsell chips were very small and similar: On the average, below 1.0 CIELAB units, for changes from D65 to M46 or M54. Future work will consider additional SPDs or lights in Mars and different irradiance values, for further theoretical comparisons and quantification of expected color changes for objects viewed in the surfaces of Mars and Earth.

PO126

DARK ADAPTATION MODELING

Nagy, B.V.[1], Seres, P.[1], Barboni, M.T.S.[2]
[1] Budapest University of Technology and Economics, Faculty of Mechanical Engineering, Department of Mechatronics, Optics and Engineering Informatics; Budapest, HUNGARY, [2] Semmelweis University, Eye Clinic, Budapest, HUNGARY
nagyb@mogi.bme.hu

Abstract

1. Motivation, specific objective

Low light levels are essential for different lighting conditions such as general public illumination, emergency lighting and special illumination. Human vision adapts to such low luminance depending on the adjusting abilities of the visual system and the sensitivity of the photoreceptors. The psychophysical measure of darkadaptometry assesses the temporal change in human visual sensitivity to low luminance stimuli. The aim of the current study was to analyse the resulting dark adaptation (DA) curves ranging from high luminance levels down to thresholds of cones and rods separately. We intended to determine specific DA parameters such as the rod-cone break time along with the cone and rod threshold luminance levels. Since DA is also used to characterize visual problems (i.e. vision related diseases), we tested our models in the case of various types of clinical diseases.

2. Methods

Standard DA protocols were used to measure human DA applying an initial full field bleaching of high luminance (7000 cd/m^2). Afterwards participants stayed in the dark looking at a frequently appearing small visual angle (approx. 1°) light stimulus with gradually reducing the luminance down to mesopic levels (approx. 10^{-2} cd/m^2) in the case of cones and to scotopic levels (approx. 10^{-4} cd/m^2) for rod threshold. Time lapse curves of the healthy and patient responses (n=13) were recorded for red and green stimuli intervened. Mathematical filtering and models were applied onto the curves to analytically find the break point where the rod curve separates from that of the cones and to measure the time and luminance when reaching thresholds.

3. Results

The results are curves of human positive perceptual responses at specific luminance levels against time. The response curves fit on the individual data initially overlap for both cones and rods and separate at the rod-cone break (usually between 5-10 min) around the cone threshold luminance. Our models show the difference between filtered and unfiltered data and hyperbolic versus various orders of polynomial fits. The break point along with cone and rod thresholds were calculated with the different approaches showing small variation for healthy controls among the different fits. On the other hand, the different patient results show high discrepancies depending on the disease and the model used. Each model was verified with the least square method to indicate the difference between model and measurement parameters. Healthy participant results generally show lower standard deviations for all parameters, while most patient results indicate rod thresholds at higher luminance levels.

4. Conclusions

The mathematical models used in our investigation, albeit being relatively complex, indicate well DA parameters in healthy participants. The resulting models may be used by lighting designers when crating low luminance illumination environment. The models may help to apply the necessary time for perception especially in the case of dynamically changing lighting where high luminance levels are followed by low levels for visual tasks (leaving a tunnel on a highway at night for example). The study also concluded to the general fact that different diseases affect DA in ways that their analysis needs to be done in separate groups

and our models may not apply to all of them. These result may help when designing illumination for patient homes and healthcare facilities.

PO131

COLOR DISCRIMINATION AT LOW ADAPTATION LUMINANCE

Pechova, M.[1], Vik, M.[1]
[1] Technical University of Liberec, Liberec, CZECH REPUBLIC
marcela.pechova@tul.cz

Abstract

1. Motivation, specific objective

Color perception and discrimination is influenced by various aspects. Among these aspects, the luminance level is also one of them. It is known that at higher luminance levels we can distinguish different shades of colors, while at lower luminance levels we gradually lose this ability. Various studies have been carried out in the past to address this issue, both in terms of the sensitivity of the eye in adapting to different levels of brightness and in terms of the sensitivity of the photoreceptors themselves (cones and rods). The adaptive mechanisms of human vision, the ability to distinguish colors, is important in many application areas such as road safety etc. In the design of suitable clothing for outdoor activities, it is therefore necessary to detail the limits of color discrimination typically in the mesopic region of luminance.

To determine whether the observer can discriminate colors, various tests have been and are being used to test for color vision deficiency. The tests are tailored to detect the observer's lack of color vision at photopic luminance, or his ability to discriminate colors. One of these tests is the Farnsworth-Munsell 100 Hue test (FM 100 Hue test), which is easy to use and understand even for lay people who have no experience in the field of colorimetry. The aim of this work was to determine whether and how an observer can discriminate colors at low luminance on the border of mesopic and scotopic vision.

2. Methods

The experiment was conducted in a light box with a simulator of the standard D65 light type based on the F7 fluorescent lamp. The trace luminance was controlled using a set of neutral density filters covering the light sources in the light box. The experiment consisted of 8 brightness levels ranging from 371, 202, 32, 6, 0.93, 0.25, 0.05 to 0.01 cd.m^{-2}. The light box was painted with a light grey paint with a brightness of Yb = 41.92.

A total of 17 observers, eleven females and six males, participated in the visual testing. Each of the participating observers was tested using the FM 100 Hue test at the above brightness at 5 repetitions. To eliminate visual fatigue, testing was spread over 4 days, where the discrimination ability was first observed at the higher luminance level and then at the lower luminance level. With this scenario, it was possible to shorten the adaptation times for the lowest luminance levels and the resulting scenario was as follows: The adaptation time was gradually increased as the luminance level decreased with an increase of 2 minutes. That is, 2 minutes at the first luminance level, 4 minutes at the second, and 16 minutes at the last luminance level.

3. Results

According to the result of the FM 100 Hue test, observers were divided into superior (with superior color discrimination), average (with average color discrimination), and low (with low color discrimination) observers. This division was made at an adaptive luminance of 202 cd.m^{-2}, as this level corresponds to the most common luminance level at which the FM 100 Hue test is performed. At this level, 10 observers were assigned to the superior group and 7 observers to the average group, and none of the observers were assigned to the low category (with low color discrimination). From the results of all observers, it was found that there is a

gradual loss of color discrimination, especially in the red and yellow parts of the chips, due to the decreasing luminance level. This was reflected by an increase in the total error score (TES). The resulting TES score at low luminance levels is consistent with the assumption that observers are unable to discriminate colors near the limit of scotopic luminance levels. For both groups of observers (average and excellent), there was a gradual loss of color discrimination due to a decrease in adaptive luminance. At the same time, the differences in TES between the two groups gradually disappeared. At the highest level of adaptive luminance, the difference in TES between the two groups was 55%. As adaptive luminance decreased, the difference between the two groups of observers decreased. At the lowest adaptive luminance of 0.01 $cd.m^{-2}$, the difference in mean TES score between the two groups was 2.15%. It was also found that the highest gradient of increase in TES was 0.93 and 0.25 $cd.m^{-2}$ for both groups of observers in the luminance region. Another finding that is associated with a decrease in luminance level is the occurrence of the pseudo-tritanopia effect in 2/3 of the observers at a range between 0.25 $cd.m^{-2}$ and 0.05 $cd.m^{-2}$, i.e. at the same luminance level.

4. Conclusions

The obtained results showed that the course of the decrease in the discriminative power towards individual colors is dependent on the hue angle of the considered colors. Firstly, the ability to discriminate colors in the red color tone region deteriorates, which is followed in some cases by a more pronounced deterioration of discrimination in the yellow and blue color tone regions. Given that the decrease in color discrimination on the tritanopic line was observed in 2/3 of the observers, whereas in the remaining observers "only" an overall deterioration in discriminability manifested by more pronounced confusions of the positions of the color chips could be observed, it can be speculated that this effect may be the result of some fluctuation in the relative ratio of L:M:S chips compared to the average observer. This result can be used to make recommendations on how different design patterns should be combined on clothing for different leisure activities to increase their discriminability in potential low light conditions.

PO135

PROTOCOL TO SIMULATE AND EVALUATE SUNGLASS FILTERED COLOUR VISION THROUGH IMAGE COLOUR APPEARANCE MODELLING

Raza, A.[1,2], Jost, S.[1], Dumortier, D[1], Dubail, M.[2].
[1]Univ Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS, UMR5513, 69518 Vaulx-en-Velin, FRANCE; [2]EssilorLuxottica, Paris, FRANCE
aiman.raza@entpe.fr

Abstract

1. Motivation, specific objective

Sunglasses today not only offer protection against glare and harmful sun rays but also potentially improve visual experience by modifying colour contrasts at wavelengths that matter as per specific activities (sports, driving, etc.). Currently, the industry does not have standardized methods for characterizing and putting forward these innovations using real 2D scenes. This work establishes a streamlined protocol to visualize and assess sunglass filtered vision on natural/urban images via colour corrected simulations.

2. Methods

The proposed method relies on the use of hyperspectral imaging and colour appearance modelling. The simulation of sunglasses on a complex scene that accurately reproduces the wearer’s colour perception requires: (1) A hyperspectral image of a complex scene which is representative of real-life situations where sunglasses are worn; and, (2) A proper mathematical function (Colour Appearance Model, or CAM) that calculates the colour perception phenomenon associated with size, shape, colour and many other properties that dictate the perception of colours by humans in complex scenarios.

Applying the spectral transmission factor of a desired sunglass on the hyperspectral image (through multiplication) produces a filtered hyperspectral image. Using the CIE colour matching functions, a 2D image is produced that is further colour-corrected through a Colour Appearance Model (CAM).

The major innovation in the proposed method relates to the use of hyperspectral images that offer colour information not just for the broad wavelengths (RGB) but for the entire spectrum (UV, visual, or IR). These more detailed images contain information that offers non-invasive methods to analyse object properties, ranging from their colour content, colour appearances, and reflective properties. These hyperspectral images, when combined with sunglass properties, offer the possibility to simulate sunglass filtered vision on real scenes with high precision.

The use of hyperspectral imaging is combined with yet another technology: image Colour Appearance Models or iCAMs (specifically iCAM06). CAMs ensure that the final rendered colours of objects resemble closely that of the real objects and take into account various visual phenomena and visual properties of the target object. Though, standard CAMs treat objects as points without taking into consideration the spatial aspects of human vision. Image CAMs remove this barrier and provide an opportunity to simulate colour vision on a 2D scale and consider the spatial aspect of human vision, thus bringing the images much closer to reality. Image CAMs also include techniques that enable simulating scenes with a large dynamic of light levels on display devices with a limited range of light levels, by compressing the variations and creating a perceptually closer version of the real scene. This further brings the images closer to reality by respecting the perceptual accuracy of colours and light levels.

3. Results

The accuracy of the reproduction depends on the choice of parameters used for the hyperspectral capture (spectral resolution, spatial resolution, signal-to-noise ratio, etc.) and for the colour appearance model (chromatic adaptation model, white-point, degree of

chromatic adaptation, etc.). To identify the optimal value/model for these parameters that improve the colour reproduction accuracy of the chosen method, a series of tests and trials are proposed. These modifications are tested via objective methods (colour difference) for hyperspectral capture parameters and subjective methods (psychophysical experiments) for the choice of CAM and its parameters.

4. Conclusions

This work proposed a process to accurately simulate complex colour vision as seen through sunglasses with the help of image colour appearance modelling and hyperspectral imaging. With the help of psycho-visual testing, we ensured the efficiency of our chosen method for the simulation of hyperspectral images via iCAM06. The optimization of hyperspectral image acquisitioning parameters and image treatment via iCAM06 will ensure that the simulation of sunglasses is accurate and faithfully reproduces the vision improvements/modifications brought in by sunglasses. This work thus created, implemented, and characterized a robust methodology to produce high fidelity images for a variety of sunglasses on a diverse range of scenes.

PO146

OBSERVATION OF ADAPTED WHITE UNDER DIFFERENT STATES OF CHROMATIC ADAPTATION

Urbin, Á.
Department of Mechatronics, Optics and Mechanical Engineering Informatics, Faculty of Mechanical Engineering, Budapest University of Technology and Economics, Budapest, HUNGARY
urbin.agnes@gpk.bme.hu

Abstract

1. Motivation, specific objective

The objective of our study was to observe adapted white under different coloured lights and different fields of view.

2. Methods

In the study, the adaptive shift was observed through the perception of white. Subjects had to adjust chromaticity on a digital display to set neutral chromaticity under different states of chromatic adaptation in coloured environments provided by a spectrally tuneable light booth.

Based on former experiments, nine chromaticities were defined in the experimental design: a white point as a reference, and four chromaticity-pairs, defining four adapting axes (each crossing the white reference point). Twenty-six normal colour observers performed the tests in all nine environments, with unaided eyes and wearing special glasses, limiting their field of view to approximately 70°.

Results were evaluated in the CIE 1976 UCS Diagram. The standard deviation and the distribution of the neutral settings were analysed based on the area and the orientation of ellipses fitted to the data with the least squares method.

3. Results

Based on the evaluated data, the significance of the aperture was not explicitly relevant. However, there were differences in the distances of the ellipses from the adapting axes and the angles between the orientations of the fitted ellipses and the adapting axes. Sensitivity in the blue-yellow direction appears lower, as the standard deviation was higher than that in the red-green direction.

4. Conclusions

The initial results indicate the effect of the adapting chromaticity on the adapting shift and the degree of chromatic adaptation.

PO148

STUDY OF INTER-INSTRUMENT AGREEMENT IN WHITENESS MEASUREMENTS

Vik, M.[1], Viková, M.[1]
[1] Technical University of Liberec, Liberec, CZECH REPUBLIC
michal.vik@tul.cz

Abstract

1. Motivation, specific objective

The pulp and paper, textile and other industries measure near white materials with well-defined d:8° or d:0° geometry. Many of measured near white materials contain fluorescent whitening agents (FWA). The current CIE Whiteness Index can only be used for samples that do not differ much in color and fluorescence and that are measured on the same instrument at nearly the same time. Within these restrictions, the CIE Whiteness Index provide relative evaluation of whiteness if measuring devices having suitable modern and commercially available facilities and are under relevant maintenance. These restriction cause problems for industry, where quality control of commercial products, communication between producer and customer require measurements be made by different devices and frequently not at nearly the same time. General recommendation in case of fluorescent materials measurement is use of two-monochromator method and 45°:0° geometry. Two-monochromator device such as spectrofluorometer is a device equipped with a source of irradiation, two monochromators and a detector. Sample can be measured with use of this device at independently controlled excitation and emission wavelengths. Disadvantage for mentioned industry is duration of measurement of whole excitation-emission matrix (EEM) and employment of experienced operator. Abridged measurements with single-monochromator instruments are therefore still preferred by industry. Main motivation of this work was comparison by industry currently used devices.

2. Methods

It was collected set of 140 near white samples containing textiles, pulp, paper, plastic and ceramic tiles. The range of CIE Whiteness Index was 9 to 150 units and CIE Tint Index range was -4 to +4 units. Every sample was measured 5 times and mean value with standard deviation was determined. Seven industrial benchtop devices equipped by integrating sphere and three industrial benchtop devices equipped by bidirectional geometry (45°a:0° or 0°:45°a). Mode of devices with integrating sphere was specular component excluded (de:8° or d:0°).

The photometric scale adjustment of the instruments was made by original tiles and controlled with use of set of Spectralon® Diffuse Reflectance Standards (Labsphere) that have known reflectance values ranging from 2% to 99%. UV calibration was performed according to manufacturer instruction using a set of white textile reference specimens calibrated by the Hohenstein Institute and alternatively with use a traceable whiteness standard measured at NRC Canada.

After each calibration process a set of 8 Spectralon® Color Standards (Labsphere) with reference data was measured to verify the colorimetric accuracy of the tested instruments with the given setup. All measurement was made in conditioned laboratory with 20±1°C and relative humidity 60±3%.

3. Results

The color measuring accuracy of all tested devices was below 0.7 CIELAB units. One of tested benchtop devices equipped with integrating sphere was rejected from study due to problem with less amount of UV radiation and possible yellowing of sphere that disturb

achievement of necessary whiteness values of reference specimens, traceable whiteness standard respectively. Measured data of CIE Whiteness Index (CIE WI) were correlated well in case of near white materials with matte surface, only one of tested devices in integrating sphere category gives values outside of 95% confidence interval of average values. In case of comparison of measured data of CIE WI between bidirectional devices and devices with integrating sphere was correlation coefficient above 0.92. Significant difference was found in case of near white samples with glossy surface, where CIE WI values measured on devices with 0°:45°a geometry approximately 10 units higher than mean value measured on devices with integrating sphere. This effect is relating to higher reflectance factor of these samples caused by its gloss. In case of CIE Tint Index (CIE TI) is situation differ and these results may be not easily explained as UV calibration effect. The method proposed by Rolf Griesser allowing computing of necessary adjustment of device dependent coefficient in case of non-neutral transfer standards (CIBA Plastic White Samples set, AVIAN ACRYLIC WHITENESS STANDARDS, etc.) allows also significant improvement of correlation between tested devices for CIE TI. Nevertheless, these coefficients are necessary to compute with use of selected samples that are on expected parallel line of linear trend of CIE TI. In other cases, the correction is affected by differences in spectral profile of fluorescence of used transfer standards.

4. Conclusions

The presented results show significant improvement of abridged whiteness measurement when is used Ganz-Griesser calibration method. Further investigations are necessary to discover disagreement between devices equipped with 0°:45°a geometry and de:8°(0°) or 45°a:0° viewing geometries in case of glossy samples. As possible improvement of inter-instrument agreement in whiteness measurements appear use of set of transfer standards allowing computing device dependent correction factors.

PO149

STUDY OF EXPOSURE CONDITION WITH RELATION TO COLOR CHANGE OF PHOTOCHROMIC SUBSTRATES

Viková, M.[1], Vik, M.[1]
[1] Technical University of Liberec, Liberec, CZECH REPUBLIC
martina.vikova@tul.cz

Abstract

1. Motivation

Chromic materials, frequently called as color-changeable materials, became more important in many applications. For example, photochromic colorants are used as in adaptive sunglasses, rewritable CD and its alternatives, indicators, etc. Photochromic dye reversible changes their color with the incoming light intensity or spectral distribution of the light. They are nearly invisible when they are not exposed to UV light; exposure to UV light causes fast transition and increasing of color depth. Because photochromic materials are based on generally unstable organic molecules, one of important characteristics relating to optical properties of such kind of materials is relating to kinetic of color change itself. Obvious in literature mentioned description of experimental method used during test of optical properties of photochromic materials is reduced on used conventional UV-VIS spectro-photometer, wavelength and power of exposure light source that is necessary to ad as accessory. Necessary information about irradiance of tested sample is obviously missing, which cause problems with comparison of data measured on different laboratories. Additional problem with the measurement of the kinetic behavior of opaque photochromic substrates with a commercial spectrophotometer is the relatively long period of time between individual measurements (cca 5 s) and the difficulty in measuring all the color change during exposure without interruption from illumination of the sample during measurement. That means commercial spectrophotometers enable off-line measurement of kinetic behavior during exposure period and quasi on-line measurement during the reversion period. The difference in the time delay between exposure and real measurement of photochromic change affects the validity of the measured data. Based on that it was decided to check influence of used irradiance and setup of testing cycle on obtained results in case of color depth measured as K/S value, half-life of color change and possible fading effect.

2. Methods

Materials: chemically pre-treated 100% cotton plain weave structured fabric with density of 135 g.m^{-2}, a yarn count of 46 threads.cm^{-1} in the warp and a yarn count density of 27 threads.cm^{-1} in the weft. The various concentrations of 3 inks containing microcapsules of photochromic dye were applied using the screen-printing method (80 mesh, speed of machine 0.15 m.s^{-1}). Used device was Zimmer MINI-MD-F Strike-Off Machine. After printing, the samples were dried 3 mins at 120 °C in Mathis LABDRYER LTE. For the preparation of printing pastes, the following auxiliaries were used: glycerin, Lukosan S (defoamer produced by Lučební závody Kolín, CZ), Sokrat 4924 (binder, CHZ Sokolov, CZ), Acramin BA (binder, Bayer, Germany), ammonia and Lambicol L90 S (thickener, Lamberti, ITA).

The measurement of reflectance factor was carried out with PHOTOCHROM 2 device developed at Technical University of Liberec. This bench-top apparatus is based on double beam spectrophotometer equipped with integrating sphere of 156 mm in diameter. As exposure light source was used high power LED with peak wavelength 385 nm and output power 1650 mW (Thorlabs, Germany). Output power, irradiance respectively was controlled by current controller allowing continuous or stepwise control of current in range 0-1000 mA at constant voltage 3.9 V. In this experiment were chosen 8 irradiances: 25, 50, 100, 250, 500, 1000, 2500 and 5000 μW.cm^{-2}.

Effect of exposure duration was tested with use of 3 set of asymmetrical cycles. First cycle set was based on 10 s exposure - growth phase when UV LED was switch ON and 300 s of decay phase when UV LED was switch OFF and 5 replication of whole cycle, second and third cycle set were differed only in exposure time, that means: second cycle set contains 30 s exposure time and third cycle set 60 s exposure time. These conditions were selected based on previous experiment made with similar samples of photochromic textiles.

3. Results

It was found that bellow photochromic dye specific value of irradiance the half-life of color change is increasing, and this value is dependent on tested concentration of photochromic ink. Possible explanation of this phenomena is influence of balance between forward and reverse reaction of photochromic dye. That means in case of low excitation energy of photochromic molecule during exposure phase the reverse reaction that is promoted typically by VIS part of light and heat can block effectively creation of transition form of molecule that is colored.

As second output of this experiment was found that exposure time of 10 s was too short for two photochromic dye that were tested when irradiance was less than 1000 μW.cm^{-2}. In case of third spirooxazine based photochromic dye was upper plateau of photochromic color change found for irradiance 250 μW.cm^{-2} and higher.

Third important result show that irradiance above 2500 μW.cm^{-2} caused short-term fading of photochromic dye during exposure phase mainly when was used longer time (60 s), nevertheless such fading was measurable only during this phase and system recover during 300 s long decay phase, when the exposure light source is switch off. On the other side all tested photochromic pigments show cumulative fading caused by irradiance of 5000 μW.cm^{-2}, that means every next cycle in cycle set (5 cycles) show decay of K/S value.

As last output of this experiment that is possible to discuss was confirmation of repeatability and reproducibility of reading made on PHOTOCHROM 2 device that is comparable with commercial bench-top devices.

4. Conclusions

Results obtained during described experiments show importance of conditions during measurement of photochromic color change. As important factor was found beside irradiance level of tested sample also setup of testing cycle that monitor growth and decay phase of color change of photochromic dye. Simply, dose of energy that is used during experiment can affect significantly obtained data and relating comparison of photochromic systems. In case of possible production of commercial devices allowing such dynamic colors measurement it is important to relate used components to expected application or rather to international standards describing sunlight irradiance at specific wavelengths and location.

PO170

VISIBILITY MODEL OF THE PHANTOM ARRAY EFFECT

Lee, C-S.[1], Kang, H.[1], Pak, H.S.[1]
[1] Yeungnam University, Gyeongsan, REP. OF KOREA
chansu@ynu.ac.kr, hye-ran@yu.ac.kr

Abstract

1. Motivation

This paper presents a new analytic visibility model of the phantom array effect. The phantom array effect can is visible during saccadic eye movement across a temporally modulated light source. The threshold frequency of the visibility of the phantom array effect can be affected by luminance, chromaticity, modulation depth, geometric characteristics of the light source, and saccadic eye movement speed.

2. Methods

We model the perception of the phantom array as a detection of spatially spread modulation interval by saccadic eye movement from temporal modulation of the light sources.

3. Results

The spatial integration model by Ricco's model is used to find out the interval to be perceived in addition to the spatial contrast sensitivity. Eye movement speed is also considered and interpreted by the spread of the temporally modulated signals. Temporal integration also provides a limit to the modulation as well.

4. Conclusions

The proposed model will be useful for the prediction of the visibility of the phantom array for given conditions. In addition, the model is useful for the metric development of the phantom array effect.

PO178

DAYLIGHT SPECTRUM INDEX: MEASURING THE DAYLIGHTING AFFINITY OF ELECTRIC LIGHTS

Bustamante, P.[1]; Acosta, I.[1]; Campano M.A.[1]; Roldán, A.[1]
[1] Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, 41014 Sevilla, SPAIN
bustamante@us.es

Abstract

1. Motivation, specific objective

The current scenario of colorimetry shows a wide variety of different metrics which do not converge in the assessment of the colour rendering of light sources. The limitations of the Colour Rendering Index (CRI) have led to the emergence of new metrics, such as the Colour Quality Scale (CQS). As in the case of the previous metric, these new concepts are based on the analysis of the deviation of different colour samples in a colour space, contrasting the results with those obtained with a reference light source, which may vary depending on the colour temperature. Within this context, the Daylight Spectrum Index (DSI) is proposed. This new concept aims to determine the affinity with daylighting of electric light sources, by comparing the resulting Spectral Power Distributions (SPD) of the studied lamps and those observed under daylight. The proposed new metric is evaluated Based on the results obtained from 560 surveys, demonstrating the usefulness of this new concept in the quantification of the chromatic performance of LED lamps and the affinity of electric light sources with daylighting.

The aim of this study is to assess a new metric which serves to quantify the affinity of electric light sources to daylighting. This new concept may be of particular interest in those contexts where colour perception must be close to that observed under daylighting conditions. Consequently, the DSI is defined in order to provide an objective definition for evaluating the affinity of electric light sources with daylighting. This new concept may serve to complement other current procedures, such as TM-30-15 or CIE 2017.

2. Methods

The new metric has as reference of daylighting, as its colour reproduction can be considered perfect. Therefore, the calculation of this new parameter is based on the comparison of SPD and the perception by both daylight and the studied light source.

Once the new metric is determined from the spectral study, its accuracy is evaluated using a light source test box. While this methodology is similar to those proposed by other authors, it offers new nuances that highlight the innovative aspects of this study, as detailed below:

- The accuracy of the new metric is evaluated through 80 colour rendering performance question sheets of 7 different light sources totaling 560 surveys. The sample in this study is significantly larger than that of previous research, providing considerable accuracy to the conclusions drawn.
- Both colour reproduction and daylighting affinity are evaluated through the results observed in the surveys, as well as the chromatic saturation of the samples.
- The new metric is compared with the results obtained from other colour rendering metrics such as CRI, CQS, Gamut Area Index (GAI), and TM-30-15.

The Daylight Spectrum Index (DSI) is defined as the ratio of the area bounded by the colour perception of the SPD of a light source studied and that which is limited by daylight. In other words, the DSI represents the affinity of the light source perception to daylight according to its SPD.

3. Results

As expected, daylight allows the highest colour rendering of the samples inside the testing box. The LED lamps with a Correlated Colour Temperature (CCT) between 4000 and 6500 K produce a better rendering than the rest of light sources. This is really worth noting, as according to CRI metric, the incandescent lamp produces a perfect colour rendering, unlike the other luminaires. In fact, the fluorescent lamp with a cool CCT allows a better colour performance than the incandescent lamp. Consequently, the CRI metric does not provide a suitable quantification of the colour performance of LED lamps, confirming previous researches.

In accordance with the previous statement, warm light sources allow a lower colour rendering, since they differ from natural light. This is the case for the LED lamp with a CCT of 2700 K, the incandescent lamp, and the warm fluorescent lamp, all of which show a deduced colour rendering between 67% and 87%.

It can be deducted that the SPD of a light source is essential to determine the hue saturation produced. Accordingly, the higher colour saturation for the lamp is observed for the dominant range of its spectral distribution.

Cool lamps, such as the neutral and cool LED as well as the cool fluorescent light source, provide a higher affinity to daylight conditions, obtaining a score between 82% and 88%. Therefore, it can be concluded that CCT is decisive in determining the affinity of a light source to a natural environment.

The metrics tend to overestimate the colour performance of incandescent lamps, while LED lamps are usually undervalued. Moreover, DSI demonstrates a noticeable performance in evaluating the colour rendering for LED lamps analyzed, showing a relative divergence with the surveys assessed of only 12%. This metric also determines the most realistic colour perception for incandescent lamps, as its overestimation for this type of light source is only 11%.

4. Conclusions

In this study, both GAI and DSI appear to be notably accurate in interpreting colour reproduction for LED lamps. Similarly, CQS and TM-30-15 demonstrate better accuracy for fluorescent sources.

DSI allows for precise quantification of colour reproduction for LED lamps, achieving an average relative difference of 12%, which is 11% for incandescent lamps.

DSI can complement other current procedures, such as TM-30-15 or CIE 2017, by providing information on the fidelity of the studied light source with respect to daylighting.

It should also be noted that LED lamps provide the best colour performance of all luminaire. Specifically, LED lamps with a colour temperature between 4000 and 6500 K produce better reproduction than other light sources. This, coupled with the better energy efficiency of this type of lamp and balanced saturation for all hues.

As expected, in the specific case of colour saturation, it can be concluded that the dominant spectrum generated by the lamp determines the range of hues where saturation is highest.

Finally, a clear relationship can be confirmed between colour reproduction and affinity with daylight conditions, acting as the main reference light source to determine individuals' colour perception.

PO09

ANGULAR DEPENDENCY OF THE LIMITING PHOTOMETRIC DISTANCE

Dotreppe, G.M.[1], Scheir, G.H.[1], Jacobs, V.A.[1]
[1] Vrije Universiteit Brussel, Brussels, BELGIUM
guillaume.mario.dotreppe@vub.be

Abstract

1. Motivation, specific objective

The limiting photometric distance (LPD) is the threshold distance between far-field and near-field, amongst others, used to set the minimal measurement distance in far-field goniophotometry. Traditionally this distance is determined along the optical axis of a light source and considered constant for all emission angles. However, an angular dependency of the LPD is expected depending on the luminous intensity distribution (LID). In the far-field, light sources can be approximated by a point whose apex is the origin of the LID. In this region, the inverse square law (ISL) can be used to assess the illuminance. In the near-field, the light source's finite surface area must be considered. Hence illuminance estimations require the computation of a surface integral to consider the extended nature of the light source at small distances. The LPD is thus a determining factor to assess the applicability of the ISL.

Norms on photometry, such as the CIE S 025/E:2015, give guidelines about the LPD depending on the LID. However, these guidelines are confusing and lack details for more complex light distributions. Some research has been carried out in the past years but diverging results have been observed and no real consensus is reached regarding the LPD.

Therefore, this study aims to give guidelines about the applicability of the point source approximation for off-axis direction based on an angular region where the LPD as determined on-axis is valid.

2. Methods

To assess the angular dependence of the LPD, a quick and easy method to evaluate the near-field illuminance is required. Analytical solutions are limited to specific scenarios; hence, a numerical approach has been taken to compute the illuminance at any point in space. To this end, the luminance is assumed to be uniformly distributed across the surface of the light source and discretised to obtain a finite sum as an approximation of the surface integral. The approach was validated against direct illuminance measurements and ray tracing simulations for three different light sources (Round OLED, Square OLED and narrow beam LED).

The illuminance in the near- and far-field are assessed numerically and compared to the illuminance estimation through the inverse square law. Whenever the relative error between both reaches a value lower or equal to 1%, as per definition the far-field is reached. This approach is applied for a range of emission angles and theoretical light sources with different beam angles following a cosine behaviour.

3. Results

The direct comparison between the numerical approach, ray tracing simulations and illuminance measurements show a good agreement indicated by high fitting index values. The LPD exhibits a decreasing trend with the emission angle. It reaches a minimum value at a critical angle and then increases again. The critical angle is linked to the Full Width Half Maximum (FWHM) of the cosine modelled light source. The higher the FWHM, the lower the critical angle but the higher the LPD itself. Furthermore, a functional relationship can be found relating the critical angle with the FWHM. For angles larger than the critical angle, the LPD increases again meaning the error between the near-field illuminance approximations and the ISL increases as well. An angular region can be defined as a function of the FWHM where the on-axis LPD is valid. Illuminance estimations through the ISL for distances and angles within

this region result in errors less than or equal to 1% compared to near-field approaches. Outside this region, the error quickly rises, and the near-field computations are to be used.

4. Conclusions

A region around the optical axis is defined in which the inverse square law can safely be applied with errors lower or equal than 1%, provided the illuminance estimations are performed for distances larger than or equal to the on-axis LPD. Past the critical angle, the LPD increases quickly, and no guarantee can be given that the illuminance computed through the inverse square law is accurate. The critical angle can be computed based on the FWHM of the light source using a functional relationship obtained through a least squares curve fitting allowing for a quick assessment of the validity region of the ISL. Future work will look at more complex light sources to assess if the same or similar angular relationships are found.

PO10

LIGHTMONITOR: A NEW WEARABLE DEVICE MEASURING LIGHT SPECTRUM AND DAY/NIGHT ACTIVITY

Dumortier, D.[1], Gronfier, C.[2], Raza, A.[1]
[1] Univ Lyon, ENTPE, Ecole Centrale de Lyon, CNRS, LTDS UMR5513, Vaulx-en-Velin, FRANCE, [2] Univ. Claude Bernard Lyon 1, INSERM, CNRS, CRNL U1028 UMR5292, Bron, FRANCE
dominique.dumortier@entpe.fr

Abstract

1. Motivation

There is now strong scientific evidence that light influences our health and well-being. Light is the main synchronizer of our biological clock, it determines the timing of our sleep/wake cycle. Research has now shown that all photoreceptors (not just ipRGCs) can potentially contribute to the non-visual effects of light in humans. In its S026 standard, CIE has defined spectral sensitivity functions, quantities and metrics which are recommended to describe the ability of a lighting environment to stimulate any of the five photoreceptor types (named generically α-opic by CIE).

One of the quantities defined by CIE S026 is the α-opic irradiance which is computed by weighting spectral irradiances with the spectral sensitivity of the photoreceptor type. Corneal spectral irradiances are easy to measure in laboratory studies, this is not the case in real-life studies. The light and the position of the subjects keep changing: a classic spectrometer cannot be used. It has to be miniature, autonomous and light enough to be worn close to the eye throughout the entire day. Measuring the spectral variations of the light to which subjects are exposed in their everyday life is not enough, actimetry is also required: during the day, to produce information on subjects 'activities and during the night, to produce information on their quality of sleep and their sleep/wake cycle.

A wearable device measuring the light spectrum and activity did not exist, we decided to develop one.

2. Methods

We created a development team gathering naïve subjects and experts from the fields of chronobiology, light metrology, optoelectronics and microelectronics. Members of the team had taken part to the calibration and tests of the LightWatcher, a light dosimeter developed within the EUClock European project (2006-2011). The list of specifications for the device was drawn from the experience acquired using the LightWatcher and other systems available on the market.

The needs of both subjects and investigators were considered. Subjects wanted the device to be as small and less noticeable as possible, easy to place on an eyeglass frame during the day or on the wrist at night. The investigators wanted to monitor the progress of their study by having access to the measurements of the device during the study rather than at its end.

Regarding the measurements of spectral irradiances, the requirements were to cover the visible domain at the best spectral resolution possible, for lighting situations ranging from watching a screen in the dark to facing the sun walking outside. UV irradiance was added not only because it is harmful to the visual system but also because it is a marker of being outdoors. Temperature was also considered useful: it provides information on the subject environment and it can be used to adjust the calibration of light measuring sensors. It was agreed that all these parameters should be measured every few seconds in order to keep up with changes in the environment of the subjects. Regarding the measurements of

subjects 'activity, the requirements were to rely on standard triaxial accelerometry at a frequency of 25 Hz with a range covering sport activity.

Once the list of specifications was finalized, the electronic experts looked for available chips. Datasheets were analyzed and evaluation kits were bought to test the most promising. We played around with the settings, checking dark signals, range and linearity of the measurements…Once the chips were selected, they were put together on a board with a central unit and a clock. Further testing allowed to define altogether the frequency of the measurements, the size of the memory, the battery capacity and the operational use of the device. Then, the board was split and miniaturized leading to an operational prototype of the device.

3. Results

The device called the LIGHTMONITOR is to be worn on an eyeglass frame during the day and on the wrist at night. For this, it comes with adjustable elastic straps. It is made of two modules plugged together: one measurement module and one battery/memory module. It has a total weight of 19 g, a cross section of 1.9 cm by 1.3 cm and a full length of 8.5 cm.

Two battery/memory modules are available: one for the day and one for the night. The subjects switch modules when they move the device to the frame or to the wrist. The module which has been used is then plugged into a docking station which charges it and transfers its measurements to a secured datacenter. The investigators can check the data while the study is ongoing. Subjects can wear the device for any number of days, there is no limitation due to battery or memory.

The measurement module measures: (1) every 5 s, a photopic illuminance, 75 spectral irradiances on the visible (every 5 nm, from 390 nm to 760 nm with a mean FWHM of 20 nm), UV irradiance and temperature; (2) every 40 ms on 3 axes, acceleration (±4g) and rotation (±1000°/s). Light measuring chips are placed behind a PTFE diffuser. They are calibrated using a side by side comparison with a reference spectrometer under artificial light and daylight. Overall, the device covers the range: 5 to 100000 lux. CIE S026 α-opic irradiances are computed from the 75 spectral irradiances.

4. Conclusions

The device is operational, it delivers detailed information on our real life exposure to light not available before. Fall 2023, it will be used in a clinical study to compare the light exposure and the sleep patterns of day shift and night shift hospital workers. With the help of machine learning techniques, our hope is to know enough from the measurements that subjects will not have to bother filling diaries. The experience acquired by developing and using the device will be shared within the new CIE JTC20.

PO22

SPECTRAL RECONSTRUCTION AND SAMPLING FREQUENCY DECISIONS IN WEARABLE LIGHT DOSIMETRY

Seah, M., Mohamed, A., Liang, S.N., Lim, J. M. Y., **Kalavally, V.**
Department of Electrical and Computer Systems Engineering and Intelligent Lighting Laboratory, Monash University, Selangor, MALAYSIA
vineetha@monash.edu

Abstract

1. Motivation, specific objective

Many circadian-related research in the past has related daily light exposure to the human circadian rhythm. These often involve studies where light exposure and actigraphy data are collected from subjects, while also having their circadian rhythm measured via proxy biomarkers (such as dim light melatonin onset DLMO values). However, measurement inconsistencies have plagued such studies with regards to choice of dosimeters, sampling strategies, dosimeter positioning and data cleaning methods, making it difficult to scaffold research findings in this field. In the past, dosimeter limitations have resulted in light data predominantly being recorded as photopic illuminance. With the knowledge of contributions made by melanopsin in intrinsically photosensitive retinal ganglion cells (ipRGCs) to the human circadian rhythm, there is a need not just to measure photopic lux, but also the α-opic illuminances which require accurate spectral reconstruction and sound sampling strategies. This paper presents two plausible approaches to spectral reconstruction for dosimeters, one based on detector-based calibration (DC) and the other via a machine-learning (ML) model for accurate measurement of α-opic illuminances and a method to aid sampling frequency decisions.

2. Methods

The light data collection dosimeter selected for this study is an Internet-of-Things (IoT) integrated, wearable mini spectral sensor developed by the Intelligent Lighting Laboratory (ILL) at Monash University Malaysia that can log daily photopic lux (~1-50,000 lux) and α-opic illuminances exposure of an individual and can store up to ~130,000 spectral measurements, approximately ~90 days of data when logged at 60-s sampling interval.

Spectral Reconstruction: Two methods (DC and ML) of converting raw sensor measurements to illuminance values are compared for their performance. In the DC approach, sensor characteristics including effects of stray-light, dark-signal levels, saturation limits, nonlinearity, directional response and spectral response are considered. Whereas in the ML approach, a Neural Reconstruction algorithm with an intermediate Decision Tree Classifier is used to predict the incident spectrum. The light dataset used to train the machine learning model consists of 833 spectral measured from halogen lights, sunlight, fluorescent lights and LED lights (correlated colour temperature ~2,300 K to ~6,900K) with photopic lux ranging from ~0.7 lux to ~98,000 lux. The ground truth is measured using a labscale spectrophotometer (CL-500A). Comparisons are made between the two methods by recording measurements of light spectra from diverse lighting conditions to those from CL-500A.

Sampling Frequency and Dosimeter Positioning: To make comparisons between different sampling intervals and dosimeter positioning, light data is collected from four sensors worn by a subject across four days during which the subject was active: two at the eye-level, one at the chest-level, and one at the wrist-level. The devices are configured to log data at 30-s intervals. To compare between different light datasets, mean absolute percentage errors (MAPEs) and the Pearson correlation coefficient (r) value are used. MAPE represents how close the light levels at each time point are, and r value represents how similar are the light exposure patterns between the datasets. First, a sampling interval that befits the study or the minimum integration time of the dosimeter, whichever is higher, is selected. The eye-level datasets are extracted to simulate similar datasets collected at longer sampling intervals. For

example, all other datapoints in the 30-s dataset are removed to simulate a dataset collected at 60-s sampling interval. This is done to simulate eye-level datasets collected at 60-s, 90-s, 120-s, 150-s and 180-s sampling intervals. The removed datapoints are replaced using linear interpolation so that the total number of data points in the simulated datasets match those of the original datasets. The MAPEs and *r* values of these simulated datasets are calculated ad evaluated with respect to the original eye-level datasets collected at 30-s intervals. Once a sampling interval is selected, the chest- and wrist-level datasets are extracted to simulate datasets collected at the selected sampling interval. The MAPEs and *r* values of the simulated chest- and wrist-level datasets are obtained with respect to the simulated eye-level datasets and compared. This helps us understand at which level the light levels represent those collected at eye-level more closely.

3. Results

In general, when comparing measurement results between the two methods, it was found that the DC method of spectral reconstruction is more consistent than the ML method across diverse lighting conditions, especially for outdoor lighting. DC method however tends to have worse S-cone illuminance measurements than ML, while ML performs better for LEDs and fluorescent light measurements. Thus if light measurements are done indoors, ML would provide high accuracy. In terms of sampling intervals, only the 60-s sampling interval dataset has an acceptable MAPE (around or below 30%) and *r* value (~0.8) when compared to the 30-s dataset. Hence, it is recommended in this framework that 60-s is used for the sampling interval, which will allow the sensor to log data for approximately 90 days with a daily recharge period of 60 minutes. In terms of dosimeter positioning, the chest-level datasets consistently have lower MAPEs and higher *r* values than those of the wrist-level datasets (chest: MAPE ~40 – 60%, *r* ~0.8 – 1; eye: MAPE ~50 – 120%, *r* ~0.6 – 0.7). Therefore, the recommendation that the dosimeter should be worn around the neck at chest-level for light data collection that represents those done at eye-level is further supported.

4. Conclusions

Overall, DC method provides more accurate spectral reconstruction compared to ML method for the current choice of training data. An observation is that the collection of sunlight data for training the ML model is ridden with uncertainties due to the dynamic nature of sunlight and is likely contributing to the poorer performance. 90 days of light data can be stored if they are collected at the recommended sampling interval (60-s) which has been shown to have acceptable MAPEs and *r* values. The sensor should be worn at chest-level as light levels collected at this position more closely resemble those collected at eye-level. The development of a complete framework including data cleaning and actigraphy validation for daily light data collection is currently in progress and will be reported in the near future.

PO30

RESEARCH ON THE DETERMINATION OF THE REFERENCE IN MEASUREMENT OF THE OPTICAL FIELD OF NED

Pan, J.G.[1], Song, L.[1], Yang, X.[1], Li, Q.[1]
[1] EVERFINE Corporation, Hangzhou, Zhejiang, CHINA
tech@everfine.cn

Abstract

1. Motivation, specific objective

For the past few years, a large number of innovative technologies and mature products have been introduced into the Near Eye Display (NED) industry. With the flourishing of the concept of “Meta-verse”, it is widely considered that the NED industry will see its fast growth in the near future. Therefore, instruments, techniques, and standards will be urgently required for accurate evaluation of NED during R&D and production quality inspection. The fact that characterization methods of NED differs a lot from that of traditional displays brings big challenges for NED measurement along with the unprecedented attention.

The basis for accurate characterization of NED is to precisely determine the reference of the optical field, which is the exit pupil, eye point and optical axis. According to the relevant standards, the optical field parameters are measured on the basis of the defined Cartesian coordinate system, which sets coordinate point (0,0,0) at the eye point, the x-y coordinate plane at the exit pupil, and the z axis along the optical axis. For the measurement of photometrics such as field of view(FOV), luminance, color, distortion, ghost effect and so on, the first step is to place the entrance pupil of optical measurement instrument at the eye point, while the optical axis of the luminance meter is set along the optical axis of the NED. In addition, the luminance meter of aiming point type needs to rotate around the eye point to trace the eye ball movement during its measurement of photometrics at different virtual image positions.

As the state of the art, the optical reference is determined via the Eye-box of NED. In the Eye-box of NED, the largest cross section parallel to the end of the optical structure is the exit pupil, of which the middle point is the eye point and the normal axis of the exit pupil going through it is the optical axis. As one can see, the key to the determination of the optical reference by conventional evaluation method is to find the Eye-box. Most commonly, the Eye-box can be measured by a luminance meter of aiming point type in certain steps. Firstly, aim the sampling point of the luminance meter at the edge of the virtual image, and record the luminance variation as the meter moves. When the luminance variation reaches the setting threshold, normally 50% of the initial value, meaning the meter arrives at the edge of the Eye-box. Secondly, apply the same strategy in all directions to decide the whole dimension of the Eye-box. During this process, the luminance meter has to rotate by a certain angle to ensure a fixed aiming point. As can be seen, this commonly used method is quite time consuming while the measurement error caused by positioning misalignment can be enormous. In addition, the optical reference can be falsely determined if the actual exit pupil plane of the NED is not parallel to the end of the optical structure, which magnifies the error.

To overcome the dilemma in the conventional method, this paper proposes a new method for the determination of the optical reference in the measurement of the optical field of NED, which aims at solving the problems of current technologies for NED measurements, such as eye point and optical axis measurement error, complicated operation, and low efficiency.

2. Methods

Based on the universal principles for NED display optics, the characteristics of the NED light beam is analyzed. Within the area of the Eye-box, the illuminance distribution pattern of different cross sections of the Eye-box is utilized to obtain the exit pupil, the optical axis, and the eye point of the NED through intelligent recognition algorithms.

3. Results

The reference of the optical field of NED can be measured conveniently and accurately by the measurement method provided in this paper. The principle analysis and measurement experiments show that the measurement method is not affected by the optical components and mechanical structure of NED. The theory of the algorithms and the corresponding measuring devices will be fully discussed in this paper.

4. Conclusions

The new method provides high measurement accuracy and convenient implementation, required for high precision measurement of NED.

PO33

FRAMEWORK FOR EVALUATION OF PROCEDURES FOR HDR LUMINANCE IMAGING MEASUREMENTS

Sáez, A.M.[1], Ferrero, A.[1], Ledig, J.[2], Schrader, C.[2], Gevaux, L.[3], Maltezos, E.[4]
[1] Agencia Estatal Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, [2] Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY, [3] Conservatoire National des Arts et Métiers, Paris, FRANCE, [4] Institute of Communication and Computer Systems, Athens, GREECE
angela.saez@csic.es

Abstract

1. Motivation, specific objective

Luminance distribution measurements with high dynamic range (HDR) are required for various applications (e.g. measurement of new LED- or laser-based car headlights, obtrusive light and glare evaluation of indoor and outdoor scenes) where high contrast levels exist simultaneously in one scene. The overall goal of this work is to develop a methodology to evaluate by simulation the performance of different HDR image algorithms in providing accurate luminance measurements in such high-contrast scenes, when applied to images from different cameras.

The specific objective is to develop a model-based software framework for generating an HDR-luminance image from a sequence of multiple low dynamic range (LDR) images of a ground-truth scene, aiming at evaluating the luminance measurements with different luminance spatial distributions, luminance ranges, camera-related parameters and HDR algorithms.

2. Methods

In order to accomplish this objective, different programs have been developed. As a first step, a virtual ground-truth scene needs to be created, which should coincide with the measurement of an ideal camera, devoid of experimental errors. Second, the camera response is modelled with the several types of error sources that occur in the measurement process, such as stray light, dark signal, nonlinearity, readout noise, blooming, smearing and other effects. Third, the process of camera calibration and measurement is modelled. The measurement includes the use of an HDR algorithm, where a sequence of multiple LDR images are acquired at different integration times in order to increase signal-to-noise ratio while avoiding saturation in the highest luminances, and then merged.

The evaluation of the virtual measurement from simulated camera response is based on going through the process inversely, i.e. correcting virtually from the camera response all those effects that can be corrected as for a real camera. This method allows the impact of the unreducible errors to be evaluated.

The final step is to compare the ground-truth scene with that determined by the virtual measurement. A provisional quality index has been proposed in the present work. Based on the value of this index, it is possible to study the effects in the measurement of the different involved variables, related to scene, camera, or measurement process.

3. Results

The main result is the developed software framework, which will be applied to understand how the different characterization and correction methods, camera characteristics, spatial

luminance distributions, luminance ranges and HDR algorithms may affect luminance measurements with cameras, and also glare and obtrusive light assessment.

In the conference paper, it would be demonstrated, mathematically and with figures, how different variables affect the HDR luminance measurements.

4. Conclusions

A software framework for the evaluation of procedures for HDR luminance imaging measurements has been implemented as a set of code blocks based on measurement principles and parametrization of the response of a generic camera.

With this, we expect to evaluate how different HDR algorithms applied on different scenes impact luminance measurements and, finally, to put it into practice with real situations.

This framework will be applied to understand the measurement errors observed in the evaluation of glare and obtrusive light with Imaging Luminance Measurement Devices (ILMDs).

PO35

PRECISION APPROXIMATION OF CIE 1931 COLOR-MATCHING FUNCTIONS BY ANALYTIC FUNCTIONS

Scums, D.V.
Independent metrological consultant, Minsk, BELARUS
Dmitri.V.Scums@gmail.com

Abstract

The question of the need for analytical approximation of Color-matching function was considered. An analysis of the literature was carried out and possible approaches to solving this problem were identified. On their basis, and also on the basis of our own research, a method of analytical approximation was developed that allows achieving accuracy very close to the original CIE tabular functions.

Motivation

Digitalization is becoming one of the newest and most pressing challenges for modern metrology. At the same time, the automation of the processes of calculating the measured quantities and their uncertainties makes us take a fresh look at the concepts that seem to have proved their universality over many years. An example of this is the CIE 1931 colorimetric system. Created in the era of the adding machines and the slide rules almost 100 years ago, it demonstrates amazing success while remaining the backbone of color measurements in science and technology.

But modern challenges require modern solutions. One of such problems is the estimation of the uncertainty of complex colorimetric functions such as the color rendering index. In our opinion, the Monte Carlo method is the only way to estimate the uncertainties for such functions. However, the Monte Carlo method requires an extremely large number of calculations and its very sensitive to algorithms for calculating efficiency. However, the Monte Carlo method requires an extremely large number of calculations and, in order to become useful in routine laboratory calculations, is extremely demanding on the efficiency of calculation algorithms.

Methods

We have created a program for calculating the uncertainty of the color rendering index using the Monte Carlo method. Experimental studies have shown that it takes about 10 minutes of computer time to achieve the minimum required value of trys equal to 100,000 (in case of using tabular values of Color-matching function). Which is clearly unacceptable in routine measurements. An analysis of the situation showed that when using the analytical form Color matching function, this calculation time is significantly reduced.

Considering the experimental character of CMF, one hundred percent accuracy of the approximation is hardly possible. Therefore, the question arises of choosing a criterion for the minimum allowable accuracy of approximation. In this paper, as the value of the minimum allowable approximation accuracy, we took the “uncertainty of the linear interpolation” of the CMF expressed in the form of the arithmetic mean of color difference ΔE_{ab} in 19 spectra. The $\overline{\Delta Eab}$= 0,51. In more detail, this issue is considered in our work “On the question of the uncertainty of CIE 1931 Color-matching functions”.

An analysis of the literature was carried out and possible approaches to solving this problem were identified. On their basis, and also on the basis of our own research, specialized software was developed that performed the selection of optimal forms of functions and weight coefficients necessary for precision approximation. Using the obtained approximated functions was calculated $\overline{\Delta Eab}$ and it was $\overline{\Delta Eab}$ = 0,63.

Conclusion.

In contrast to a purely mathematical criterion for assessing the accuracy of the approximation, for the first time we have proposed an approach that takes into account the peculiarities of colorimetric measurements. On the basis of this approach, with the help of a four-term partially continuous Gaussian function, the CMF approximations were performed. The obtained value of accuracy significantly exceeds all other approaches proposed before and is as close as possible to that of linear interpolation - the main method approved by the CIE.

PO39

PERFORMANCE CHARACTERIZATION OF A LARGE REFURBISHED 4 m INTEGRATING SPHERE

Florian Stuker[1], Fabio Rinderer[1], Beat Imhof[1], Peter Blattner[1]
[1] Federal Institute of Metrology METAS, Bern-Wabern, SWITZERLAND
florian.stuker@metas.ch

Abstract

1. Motivation, specific objective

The unique 4 m integrating sphere built in 1965 lay unused for many years until it was decided to make a complete renovation with the help of state-of-the-art technologies. This project was triggered by a national market request to provide efficient and reliable measurements for different types of luminaires and lamps for a web platform. This web platform serves as a meta-tool for product comparison where end customers can browse similar products of different manufacturers and compare them according to different parameters such as energy efficiency. The uniqueness of this platform is the representation of measured product specification parameters and not representing the manufacturer data sheets or the minimum parameters required by the national and international regulations. Therefore, the prerequisite for the integrating sphere performance after renovation were the ability to measure the following parameters: Spectral values (irradiance, colour temperature, colour rendering index), electrical parameters (power consumption, power factor, harmonics), photometric values (luminous flux, flicker parameters, (flicker index, stroboscopic visibility measure (SVM), short term light modulation (P_{stLM})) in full load but also for different dimming levels.

2. Methods

In a first step the old sphere coating was analysed as it was yellowed and the material was unknown. Different tests for a new coating application were performed on a dismounted hatch including sandblasting before re-painting or painting over the old coating. The new paint is based on barium sulphate with black particles to achieve the desired reflectivity. At the main port behind the baffle a new fixation was designed to install a state-of-the-art spectroradiometer covering all required spectral values. The same device is also allowing a luminous flux measurement with a separated photometer detector. Platforms and installing equipment are designed to mount the different shaped and sized luminaires in the sphere centre. The speciality of this sphere is the access to the DUT via a main door and a retractable walkway. At 45° from the main port on the equator a new opening in the sphere wall was made to magnetically attach a photometer head with adequate electronics for measuring the specified flicker parameters. To install an additional feature, we used the occasion and created an additional port on the equator at -45° from the main port for installing a small fisheye-lens camera. This instrument allows light intensity distribution measurements. In combination with the spatial uniformity map of the integrating sphere the fisheye camera method helps quantifying and reducing the measurement uncertainty of luminous flux measurements. In addition, emission parameters (divergence angle, partial luminous flux,…) can be determined directly without the need for goniophotometric measurements. The spatial uniformity map was acquired with a sphere scanner. To acquire the electrical parameters of the DUT a setup is used which was developed in a former EMRP project (ENG05 Metrology for Solid-State Lighting) for electrical characterisation of solid state lighting mainly LED lamps. The temperature of the sphere and the device under test are monitored during the measurements. All these measurement parameters are integrated into a software for an efficient workflow starting from a customer request towards the data acquisition and treatment ending with the measurement report.

3. Results

The painting test showed a favourited solution of painting over the old coating achieving a reflectance of above 90% for the visible part of the spectrum. Despite the challenge of an on-site painting of such a large sphere an acceptable spatial uniformity is achieved which was

shown by the sphere scan measurements. Furthermore, the advantage to integrate the fisheye-lens camera is the ability for spatial correction, which is important for light source measurement with non-uniform angular distributions. The sensitivity of the flicker setup showed the ability to measure flicker parameters of low luminous flux lamps < 60 lm. Depending on the dimming level of the tested light sources it is important to be able to achieve reliable measurement results. The spectroradiometer and its integrated photometric sensor have no issues measuring the targeted lamps and luminaires. Moreover, we were evaluating the sphere calibration factor by incorporating the established corrections. The electrical measurement setup is for the purpose of measuring consumer products exaggerated but leads to stable and repeatable conditions for the electrical quantities. It has a high usability as the setup can be modularly integrated into the power supply network. All the measurements are directly traceable to the international system of units SI.

4. Conclusions

In summary, the newly renovated and characterized sphere is offering a measurement instrument on the latest technological level where the most important parameters of today's lighting products can be efficiently and reliably measured in a very efficient way. The large size is not only beneficiary for the specific need of this lamps and luminaire comparison platform but also for other applications such as large illuminated panel measurements.

PO41

ILLUMINANCE READINGS FROM THIRTEEN SMARTPHONES: MEASUREMENT INACCURACIES

Van Duijnhoven, J.[1], Aarts, M.P.J.[1],Mardaljevic, J.[2]
[1] Eindhoven University of Technology, Eindhoven, The NETHERLANDS, [2] Loughborough University, Loughborough, UK
j.v.duijnhoven1@tue.nl

Abstract

1. Motivation, specific objective

The main reason for using computer simulation tools in the lighting design process is to demonstrate compliance with standards. However, after installation, it is essential to perform lighting measurements to verify the installed lighting system. These measurements are mostly performed using calibrated photometers but in practice we also see the use of smartphones for indicative measurements, especially when resources (e.g., time or budget) are limited. Most modern smartphones are equipped with a photodiode that measures ambient light to, for example, adjust the screen brightness in response to the localized luminous environment. However, this measurement can also be extracted through different mobile applications; hence the possibility to use a smartphone as a photosensor.

The potential of using smartphones as photosensors has been studied before showing mixed results; however the testing procedure as well as the number of phones or mobile applications were limited. Previous studies compared illuminance readings from different smartphones using different mobile applications and reported deviations with respect to a reference luxmeter of which the technical specifications were not always provided.

In this study we tested not only deviations between the smartphones and a cosine-corrected calibrated photosensor but we also explored directional responses and linearity for different smartphones using different mobile applications. Consequently, we aim to contribute to the discussion whether or not smartphones can be used for performing illuminance measurements in the field.

2. Methods

In total, thirteen different smartphones running on Android operating systems (i.e., Huawei P10 Lite, Huawei P20 Lite, 2x LG G6, Motorola Moto G7 Plus, OnePlus 3T, OnePlus 6T, Oppo Reno4 Z 5G, 2x Samsung Galaxy A5, Samsung Galaxy S7, Samsung Galaxy A40, Samsung Galaxy Alpha) using five different mobile applications (i.e., Androsensor by Fiv Asim, Lux Meter by Waldau-webdesign.de, Light Meter by Trajkovski Labs, Lux Meter by Crunchy Bytebox, and Light Meter by My Mobile Tools Dev) were tested on their illuminance measurement accuracies. The measurement accuracies were tested by analysing directional response indices, linearity indices, and absolute correction factors. The absolute correction factors were determined by comparing the illuminance measurements of the smartphones with the calibrated reference photometer Hagner E4-X under diffuse lighting conditions (i.e., illuminance range 1200-12,000lx). The directional and linearity indices were calculated according to the procedure as described in ISO/CIE 19476:2014. The linearity indices were calculated with and without tubes placed on top of the smartphones to extend the illuminance range (i.e., low illuminance range of 100-1600lx with tubes placed on devices and high illuminance range of 1200-12,000lx without tubes placed on devices) but moreover to include or limit the angle of incidence and hence to include or limit the potential cosine error affecting the linearity index. The quality indices are evaluated according to the classes as presented in DIN 5032-7:2017 (i.e., classes L, A, B, and C – class L meaning the best performance and class C the worst).

3. Results

Considering the thirteen smartphones we tested, the illuminance values measured with the smartphones were always lower compared to the reference photometer. The correction factor varied between 1.01 and 2.56. The correction factor varied between the different mobile applications (the standard deviation over all smartphones varied from 0 to 0.0347) but moreover between the different smartphones (the standard deviation over all mobile applications varied from 0.517 to 0.524).

All smartphones seem not to be cosine-corrected (i.e., directional response indices ranging from 20% to 46%, corresponding to >class C) but the smartphones showed linear responses both within the lower illuminance range (linearity indices ranging from 0.0137% to 0.0882%, corresponding to class L) and within the higher illuminance range (linearity indices ranging from 0.0153% to 0.129%, corresponding to class L).

Even when looking at two identical smartphones, the measurement accuracies differed. For example, although the directional response indices as well as the linearity indices of two Samsung Galaxy A5 phones were similarly classified (i.e., directional response indices of 35% and 37% and linearity indices of 0.076% and 0.034%), the absolute correction factor was found to be distinctive (2.2 and 1.8).

4. Conclusions

In previous literature it was stated that the difference in accuracy of measuring illuminance with smartphones was mainly caused by the different mobile applications; however, in our study we found that the smartphone itself affected the measurement inaccuracies the most. The devices differed in brand, model, age, screen cover, casing, colour, and incorporated light sensor. Our study was limited to phones running on Android operating systems. It is recommended to investigate measurement accuracies for iOS phones as well. Furthermore, follow-up research is required to explore which factors cause the most significant measurement inaccuracies. Subsequently, a calibration protocol can be developed considering the factors that cause these measurement inaccuracies.

The study reported here shows that calibration is essential before using a smartphone as a light measurement device. Even if we would be able to correct the illuminance values measured with the smartphones with correction factors (determined by comparing these illuminance readings with illuminances measured by a reference photometer), it is important to realize that smartphones are not cosine-corrected which introduces a significant measurement error. Therefore, we recommend not to use smartphones for illuminance measurements in the field, let alone to test compliance with standards.

PO44

RESEARCH ON THE BRIGHTNESS LIMIT OF MEDIA FACADE IN MIXED COMMERCIAL AND RESIDENTIAL STREETS: TAKING HUAIHAI ROAD IN SHANGHAI AS AN EXAMPLE

Zhang, B., Chen, S.F., Zeng, X.X., Lin, Y.
University of Tongji, Shanghai, CHINA
linyi_tjcaup@tongji.edu.cn

Abstract

1. Motivation, specific objective

The《Evaluation Requirements for Obtrusive Light of LED Panels》specifies different luminance and illuminance requirements for urban residential and commercial areas. However, in the mixed commercial and residential areas of Huaihai Road in Shanghai, there are three problems that need to be addressed: 1. The brightness of a single display screen in the commercial street far exceeds the limit standard for residential areas; 2. Commercial street advertisements and display screens are set up in multiple places, and the superposition of their brightness greatly increases the illumination value of residential windows; 3. Old residential buildings are lower in height and are more affected by media facade light. Long-term exposure to high-intensity radiation can have a negative impact on people's physiology and psychology, making it necessary to limit the brightness of media facades in mixed commercial and residential streets. The aim of this study is to accurately calculate the relationship between media facade brightness and residential window illumination in a complex commercial environment.

2. Methods

This study consists of four parts: theoretical derivation, laboratory verification, error correction, and commercial and residential mixed street verification. In the first part, based on the law of solid angle projection, the quantitative relationship between different display screen brightness and window surface illumination under different relative positions and included angles is theoretically deduced. In the second part, the point luminance meter is used to test the objective brightness of the display screen at distances of 2 m, 4 m, and 6 m from the normal line of the display. The objective brightness of the display is obtained by averaging multiple sets of data, which is measured at 329 cd/m^2. Then, the illuminometer is used to test four sets of illuminance data at different positions and included angles. The first set of illuminometer data is taken at distances of 1 m, 3 m, and 5 m on the normal line of the display. The second set is taken at 3m on the normal line, with transverse distances of 1 m, 2 m, and 4 m. The third set is taken at 3m on the normal line, with a transverse distance of 3m, and included angles of -30°, 0°, 30°, 45°, 60°, 90°, and 120° (the included angles between the screen and the test screen are positive clockwise and negative counterclockwise). The third part involves the classification of different types of display devices in commercial environments and the testing of the light distribution curve of each type. In the fourth part, three types of data need to be measured: the first is the use of a point luminance meter to test the multi-point luminance on the media facade and obtain an average value; the second is the use of a laser rangefinder and tape measure to measure the media facade luminous area, media facade, and window relative position distance; and the third is the use of an illuminometer to measure the window surface illuminance.

3. Results

The results show that in laboratory verification, the brightness errors in the first group of experiments are all below 5%, and the farther the distance is, the smaller the errors are. The

error of the second group and the third group can be up to 50%, and the error increases with the increase of the Angle between the normal line of the screen and the normal line of the test plane. The data has a high correlation with the light distribution curve of the screen itself. After adding the coefficient correction to the formula, the calculation error is reduced to less than 10%. In the Huaihai Road test, the error between the test results and the calculated results is about 5%.

4. Conclusions

It is proved that the brightness and illumination data can be converted more accurately when the Angle between window normal and media facade normal is close to 0°. When the Angle between the media facade normal and the window normal is large, the LED display light distribution curve is quite different from the cosine lighting body light distribution curve, so the error also expands accordingly. The error is related to the media facade light distribution curve. Considering the media facade light distribution, the coefficient correction of the formula can reduce the calculation error.

PO45

NEW GENERATION OF REFERENCE PHOTOMETERS FOR REDUCED UNCERTAINTY

Zong, Y.[1], Teitzel, R. L.[2], Miller, C. C.[1]
[1] National Institute of Standards and Technology, Gaithersburg, MD, USA,
[2] Nanoport Technologies, Las Vegas, NV, USA
yuqin.zong@nist.gov

Abstract

1. Motivation, specific objective

To achieve the smallest measurement uncertainties in photometry, preferably, the reference photometers are calibrated for spectral irradiance responsivities directly against transfer-standard trap detectors using a tuneable laser source. However, our previous generation of reference photometers could not take this advantageous calibration method because of their interference fringes when they were exposed to a coherent laser source. In addition, those photometers were susceptible to environment conditions (e.g., temperature, dust, and moisture). These limitations of the previous reference photometers made it difficult to realize and maintain our photometry scale within a small uncertainty. To address these issues, we developed a new set of reference illuminance photometers for realization and maintenance of photometry scales with an uncertainty as small as possible.

2. Methods

The new illuminance photometer was designed to have a glass window, a Ø4 mm aperture, a photometric filter, and a silicon photodiode, which are integrated into a sealed optical chamber filled with dry nitrogen gas at one atmosphere to ensure long-term stability. The outer side of the window is polished for easy cleaning and inner side of the window is slightly ground to eliminate interference fringes effect so it can be calibrated using a tuneable laser. The photodiode has a high shunt resistance of 5 GΩ to minimize the photometer’s dark current and signal noise. The entire optical chamber is thermally insulated from the photometer housing and is temperature-regulated at 25 °C using an external temperature controller. The dimension of the cylindrical photometer is Ø63.5 mm by 71 mm. A high accuracy standalone transimpedance amplifier is used for measuring photocurrent of the illuminance photometer.

3. Results

More than 10 illuminance photometers were built. The effect of interference fringes of the new photometer was tested to be negligible (less than 0.01 %). The dark current of the new photometer was measured to be extremely low (approximately 50 fA). The new photometers have been calibrated against transfer-standard trap detectors for spectral irradiance responsivity using a tuneable laser source since 2018. The change of illuminance responsivity of the new photometer is on the level of 0.05 % per year.

4. Conclusions

The newly developed illuminance photometers enable us to realize illuminance responsivity scale using a tuneable laser calibration facility to reduce the uncertainty from >0.5 % (k = 2) to 0.20 % (k = 2). Also, the sealed, temperature-controlled design makes the new photometer long-term stable and much less susceptible to environment conditions, which is critical to maintain the realized photometry scales within a small uncertainty between two annual realizations.

PO50

DISPLAYING REAL-TIME VIDEOS IN VR FOR STUDYING DYNAMIC VIEWS-OUT IN A DAYLIT ENVIRONMENT

Cho, Y.[1], Wasilewski, S.[1], Karmann, C.[2], Andersen, M.[1]
[1] École Polytechnique Fédérale de Lausanne (EPFL), Lausanne, SWITZERLAND, [2] Karlsruhe Institute of Technology (KIT), Karlsruhe, GERMANY
yunni.cho@epfl.ch

Abstract

1. Motivation

Access to a satisfactory view of the outside is essential for building occupants' health and well-being. Previous studies have shown that specific visual elements can enhance the perceived quality of a view-out and improve occupants' satisfaction with the view. These include natural landscapes, distant features, and a diversity of visual elements. While it has been suggested that the dynamic movement and temporal changes in the content of views-out have the potential to enhance its perceived quality—by improving building occupants' awareness and connection to their surrounding environment—motion and temporal changes are largely missing from most studies to date on this topic. Current view rating metrics and representation methods often rely on static, time-independent views and cannot explicitly account for the importance of dynamic features in a view.

To address the current gap in view-out research, this study tests the suitability of a new workflow that utilizes real-time videos and Virtual Reality (VR) technology to capture dynamic daylit views. VR technology has significantly advanced studies on light perception and view-out, providing immersive depth perception and three-dimensional stereoscopic vision. Compared to experiments conducted in physical spaces, VR offers better control over environmental factors, reproducibility of results, a wider range of visual stimuli, and higher consistency in experimental conditions. However, due to limitations in luminance range, screen resolution, and field of view, VR simulations are limited in their ability to replicate the physical environment, especially when scenes include natural light and its dynamics. Most researchers attempt to address these limitations by compressing the luminance range from High Dynamic Range (HDR) photographs to a reduced dynamic range through dedicated and validated tone-mapping procedures. However, the exposure time currently required for producing HDR prevents capturing real-time video. This has limited view-out studies conducted in VR to mostly rely on photographs and renderings without including temporal changes or movements. This study challenges the current approach and provides an alternative solution for incorporating VR in daylighting and view-out research. To understand the extent to which this method is valid, we conducted a direct comparison between extracted frames from real-time videos, tone-mapped HDR photographs, and measured illuminance and luminance values.

2. Methods

The proposed method for collecting view scenes involves using a Canon RF 5.2m F2.8L Dual Fisheye lens and a Canon R5 camera. This lens has a 60mm interpupillary distance, which is similar to human vision with natural parallax, allowing for the capture of perfectly aligned 180-degree stereoscopic videos up to 8K resolution. This reduces the number of required camera angles and simplifies the editing process. To capture realistic view-out scenes, a scale model of an office room with a 0.4 aspect ratio and 48% window-to-wall ratio is used. During the scene collection process, outdoor illuminance values are recorded using an LMT lux meter near the camera setup, and luminance values are collected in HDR photographs before and after collecting the video footage using the same camera setup. These collected scenes are then converted into equirectangular projections to create stereoscopic 3D 180-degree videos for VR projection using Canon EOS VR Utility software and Adobe Premiere Pro software with an EOS VR plug-in.

3. Results

Previously, a pilot study was conducted with 34 subjects comparing perceptual impressions of window views from a real office and the same views projected in VR using the proposed scene collection method. The preliminary results from this study showed that using real-time videos combined with a scale model produces perceptually accurate view-out perception in VR. In this study, the proposed methodology's suitability is further tested by conducting comparative studies on illuminance, luminance, and contrast ratio measures initially collected in the real environment and two captured scenes: HDR photographs and real-time videos. The physical accuracy of the output scenes generated using normative tone-mapping operators (Reinhard02, Ward97, Durand02) on the HDR photographs is then analyzed in comparison to extracted frames from the automatically tone-mapped real-time videos. To understand the method's potential limitations, various scenes collected in different weather conditions and environmental contexts are compared. Overall, the study's results can be used to determine the extent to which the camera's automatic settings can retain accurate information and provide a realistic perception of daylight conditions compared to using normative tone-mapping operators for video output.

4. Conclusions

This study is the first to assess the suitability of using real-time videos in VR for studying the perception of daylit views-out using original data based on illuminance and luminance measurements. Through comparative studies, the authors evaluated both the strengths and limitations of a workflow for representing dynamic views without using normative tone-mapping operators, instead relying on the camera’s automatic tone-mapping procedures. The output of this study tests the applicability of a simplified visualization tool for representing daylit window views from office environments in a controlled and consistent manner. This work paves the way for new experimental avenues in reliably representing dynamic movements and temporal changes in views-out when conducting studies about them.

PO57

IMPLEMENTATION OF A HIGH-SPEED LED CHARACTERISATION SYSTEM

Poppe, A. [1]**,** Hegedüs, J. [1], Hantos, G.[1], Ender, F.[2]
[1] Budapest University of Technology and Economics, Faculty of Electrical Engineering and Informatics, Budapest, HUNGARY, [2] Spinsplit kft., Budapest, HUNGARY
hegedus.janos@vik.bme.hu

Abstract

1. Motivation, specific objective

One of the biggest advantages of development with an Industry 4.0 approach is that even without building a prototype of the final product, it becomes possible to plan accurately even in the development phase. In the future, the product designer or development engineer will be able to use precise computer simulations to assemble the lamp model or even the entire lighting system in order to create exactly the required lighting scheme.

A usually cloaked but all the more important pillar of the Industry 4.0 approach is the fact that accurate simulations can only and exclusively be performed with the help of the exact and perfectly lifelike models of the system components. However, making such models is never trivially simple, and in most cases it is a much more complex task. In the case of lighting solutions, at least three physical domains must be taken into account when performing the necessary simulations. In the case of semiconductor-based light sources, the electrical and thermal parameters are almost inextricably dependent on each other, and in order to achieve the complete picture, in addition to CFD (Computational Fluid Dynamics) simulations of natural or forced convection cooling solutions, it is also essential to model the optical systems at the light path level.

The modelling and simulation of complex systems is of course never done in a single step and always begins with individual characterization of the basic elements. Several cornerstones of the characterization of the individual basic components could be mentioned, and perhaps the most important of these are measurement accuracy and feasibility. A measurement that is imprecise is worthless, but at the same time, a method that is not carried out by manufacturing companies because of its excessive resource or time requirements will not be more useful either.

In the final article to be submitted, it is intended to present the implementation of an LED case-level measurement system that provides the best possible accuracy and the highest speed in order to achieve the power LED characteristics in all electrical, optical and thermal operating domains.

2. Methods

Characterisation time of a typical power LED compliant to the CIE 127:2007 Technical Report and to the JEDEC JESD 51-5x family of standards takes approximately 2…12 hours in total. The purpose of the final paper to be submitted is to provide an overview on the possible realization of our concepts aimed at high throughput LED testing. The target is to achieve at least one order of magnitude decrease in the overall testing time spent on a single LED package. The main goal of the new measurement system is to support and speed up the Delphi4LED-style LED modelling process in order to make it feasible to become an industrial standard. Furthermore, the goal is that the accelerated measurement procedure can be combined with the different LED aging tests with a realistic time requirement, with the help of which the above-mentioned Delphi4LED-style procedure can become suitable for modelling the aging of LEDs accepted even in an industrial environment.

The first approach is aimed at achieving the highest chances of industrial acceptance, is based on existing de facto industry standard. The selected hardware components are glued together with a highly customizable third-party software in order to form a single, high

throughput LED testing solution. The major hardware components are measurement equipment from various vendors that are also widely used in the solid-state lighting industry. The application level access to these measurement devices is provided by a software architecture based on an IoT (internet of things) approach, with a unique, application level data communication protocol that is supported by device specific drivers.

The second track of implementation is aimed at pushing all necessary elements of the new characterization approach of LEDs to the possible achievable physical limits, especially in terms of speed.

3. Results

The main approach is to combine an LM-80 compliant ageing test chamber with an integrating sphere, however, ageing of the test LEDs (20 pieces per board) will take place on an MCPCB outside the sphere, in a dedicated aging chamber, that way avoiding potential issues with degradation of the coating and constant occupation of the measuring sphere (which would be a case if the sphere was used also as thermal chamber for LM 80 testing).

To achieve relatively fast changes of the ambient temperature for the measurements, the test PCBs with the LED packages to be tested are mounted on the active cooling/heating cold-plate for transient and optical measurements. A Peltier-based cold-plate solution is selected that allows fast temperature change with a uniform temperature on the plate. The range of the set temperature of the plate (carrying the test PCB) is 15 to 85 °C (with maximum temperature of 120 °C achievable with a hardware upgrade).

A dual photometrical system (photodiode + spectroradiometer) allows recording of short pulses of the radiant flux at times below 1 ms, while it is still possible to achieve stable readings of spectral power distributions which requires a minimum of approximately 10 ms of exposure time. This later value determines the final throughput of the optical part of the LED characterization procedure. The importance of measuring the instantaneous radiant flux values is to derive the LED junction temperature that would belong to the average spectrum obtained during the integration time window (e.g. 10…100 ms) needed by the spectroradiomter for SPD measurements.

4. Conclusions

The final paper to be submitted will summarize the current status and future steps of the development and realization of a high-speed LED testing environment.

The new design proposed is an IoT control software based hardware integration of currently available laboratory equipment and a newly developed optical measuring system.

The novel design is a fast optical testing technique, aimed at characterizing the optical transient and the thermal transient observed after the turn-on of the LED. The added measuring capability will also provide characterization data for LEDs stressed in highly-accelerated conditions.

PO65

USING A LUMINANCE ANALYSER TO MEASURE THE LUMINANCE OF CELESTIAL BODIES DURING ECLIPSES AND OTHER ASTRONOMICAL MEASUREMENTS

Novák, F[1], Baxant, P.[1], Škoda, J.[1], Motyčka, M.[1]
[1] Faculty of Electrical Engineering and Communication
Brno University of Technology, Brno, CZECH REPUBLIC
novak1x@vutbr.cz

Abstract

1. Motivation, specific objective

The year 2022 was interesting, because it brought - among other things - solar and lunar eclipses to Europe. Both of these eclipses were partial but nevertheless significant for Europe in many ways. However, these cosmic events also provided an opportunity to quantify them precisely, namely, to measure the distribution of luminance of both celestial bodies during this relatively rare occasion with a luminance analyzer.

This somewhat unconventional use of the luminance analyzer - as a tool typically used for photometric analysis of traffic situations or artificial lighting - demonstrates its versatility and ability to be widely applicable across many disciplines.

At the same time, this paper also outlines the possibilities of using these advanced technologies to directly measure the luminance of even more distant celestial bodies, and how they can be used to quantify the degree of light pollution (or ALAN) by scaling the visibility of certain stars and other celestial bodies.

2. Methods

In both cases, the measurements took place for almost the entire duration of the named celestial phenomena, i.e., during the morning hours of 16 May 2022 for the lunar eclipse and during the afternoon of 25 October 2022 for the solar eclipse.

In addition, many other measurements with a similar purpose (i.e., to quantify the luminance of the surface of the Moon and Sun) have been made outside of these special events at other times and days.

A luminance analyzer equipped with lenses with different focal lengths was used for the measurements. In particular, a universal lens with a focal length of 135 mm was used, followed by a fisheye lens with a focal length of 4.5 mm and, for solar eclipse measurements, a 500 mm lens equipped with a teleconverter - thus the actual focal length was 1000 mm, which already allowed relatively precise observation and, above all, imaging of the solar disk. For some measurements, the instrument was mounted on a motorized astronomical mount, which can smoothly compensate for the effect of the Earth's rotation and keep the desired object permanently in the center of the field of view; for the rest of the measurements, a traditional tripod was used to stabilize the instrument.

3. Results

Even though the results were burdened with some error due to clouds and other atmospheric phenomena (especially problematic during the lunar luminance measurements) and the fact that the Moon fell below the horizon shortly after the eclipse peak, the measurements allowed us to better understand the distribution of luminance on these celestial bodies during the eclipse.

The luminance maps -and the slices made through them - have shown that while towards the edge of the solar disk its luminance decreases relatively slowly, towards the shadow of the Moon, causing the eclipse, the decrease is much more sudden and abrupt.

4. Conclusions

In this article, we described the possibilities of using a luminance analyzer for measurements in the field of astronomy, where this analyzer was used to measure the luminance of the Sun and Moon during eclipses. The resulting data gave us a reasonably accurate view of the luminance distribution on the surface of the Sun and Moon during their partial eclipses. This information further demonstrates the true multidisciplinary nature of the technical solution and its potential for astronomical measurements as well as measurements related to the luminance of the night sky and the degree of light pollution.

PO68

NOVEL MULTISPECTRAL ALPHA-OPIC AND UV CORNEAL IRRADIANCE LIGHT LOGGER WITH INTEGRATED ACCELEROMETER FOR USE IN FIELD RESEARCH

Spitschan, M.[1,2], Walzog, J.[1], Teufel, H.[1], **Guidolin, C.[2]**
[1] Max Planck Institute for Biological Cybernetics, Tuebingen, GERMANY, [2] Technical University of Munich, Munich, GERMANY
manuel.spitschan@tuebingen.mpg.de

Abstract

1. Motivation, specific objective

Light is a crucial driver of human physiology and behaviour, affecting the biological clock, hormone production and sleep. Consequently, light can be used as an intervention and a clinical target. These non-visual effects of light are due to a set of cells in the eye's retina called the intrinsically photosensitive retinal ganglion cells (ipRGCs) expressing the photopigment melanopsin. The ipRGCs are quite unlike the cones and rods, which underlie vision and visual perception. They have a spectral sensitivity with a maximum of around 490 nm. The spectral sensitivities of the ipRGCs were standardized in 2018 by the International Commission on Illumination (CIE) in the International Standard CIE S 026/E:2018. Most of what we know about these non-visual effects of light comes from very well-controlled laboratory studies, in which the light conditions are quite unlike those in the real world, which vary in intensity (several orders of magnitude), time (time-varying conditions in illumination), space (different scenes depending on the presence of light sources) and spectrum (mixtures of electric, display and daylight). To characterize light exposure of human participants living under daily conditions and build personalized predictions and interventions, it is necessary to measure light exposure. The measurement plane to determine the physiologically relevant light exposure is the corneal plane, requiring measurements near the eye. Here, we developed a novel light logger for capturing light exposure in the corneal plane.

2. Methods

We developed a novel light logger, capturing light using 18 channels in the visible and near IR range (410-940 nm) and two channels in the UV (330 nm and 365 nm) range. The sensors are commercially available. In addition to the light sensors, we have also included a 6-axis accelerometer (linear acceleration and angular velocity) to measure movement to extract information when the light logger is worn. The light logger is connected to a microcontroller for recording and storing the data. The microcontroller is connected to a computer for recording setup and data retrieval. Integration time is controlled using an adaptive mechanism for accounting for large differences in environmental illumination spanning multiple orders of magnitude. Software for analysis of the light exposure data is in preparation.

3. Results

Our preliminary calibration data show the viability of the multi-sensor approach underlying the light logger. In early tests, we tested the feasibility of long-term light exposure measurements. We are working on further miniaturization, making the light logger more robust and weather-proofing it for long-term use.

4. Conclusions

Our early tests show that our novel light logger can be used in field studies. We are expanding our test suite to develop novel ways of using the acquired light exposure data in behavioural interventions to modify light exposure to optimally support sleep, circadian rhythms and alertness. A key future functionality is the ability to transfer the light exposure data via Bluetooth to a smartphone for integration in a mobile application.

PO69

INFLUENCE OF PHOTOGRAPHIC LIGHT-SHAPING ATTACHMENTS ON COLOUR PROPERTIES OF THE ORIGINAL LIGHT SOURCE

Štampfl, V.[1], Ahtik, J.[1]

[1] University of Ljubljana, Faculty of Natural Sciences and Engineering, Department of Textiles, Graphic Arts and Design, Chair of Information and Graphic Arts Technology, Ljubljana, SLOVENIA

veronika.stampfl@ntf.uni-lj.si

Abstract

1. Motivation, specific objective

Photographic light sources are generally described by the type of light source, the power they emit in watts, the colour temperature of the emitted light in Kelvin, and the colour rendering index (CRI). To describe the light properties on the observed scene, the distance of the light source is often specified, since light intensity follows the inverse square law. These data should describe the light properties on the illuminated scene; however, light-shaping attachments are often overlooked in the accurate description of the illumination conditions.

To obtain different variations of the original illumination, light-shaping attachments are often used to change the light intensity, light quality, and colour properties. Colour gels in highly saturated levels are used for the latter. Other common photographic light-shaping attachments are used to change the quality of light by passing it through different combinations of materials. In these cases, colour differences are often neglected. The present study focuses on determining the effect of various photographic light-shaping attachments on the colour characteristics of the illuminated scene.

2. Methods

A series of photographic light sources are used to illuminate a test scene in a controlled environment, i.e. darkroom. A Gretag Macbeth ColorChecker test chart is placed on the scene from which we extract the colorimetric data. This is done automatically with a custom programme written in the Python programming language, using open-source libraries. Light-shaping attachments are then placed on the original light sources and the measurement process is repeated. The differences in illumination conditions between light sources with and without specific light shaping attachments are calculated using colorimetric equations in appropriate colour spaces.

The illumination conditions within the scene and the light characteristics of the light source are measured as a reference to allow double checking of the results. An X-Rite i1 Pro spectrophotometer is used for this purpose.

3. Results

Differences in the colour rendering of the observed scene with and without light-shaping attachments are described, analysed, and correlated in writing and visually. The results propose guidelines on appropriate usability of the tested light-shaping attachments, focusing on colour rendering ability.

4. Conclusions

Conclusions are drawn from the results that provide generalised guidelines for the usability of photographic light-shaping attachments and their influence on the colour properties of the original light source and, consequently, the illuminated scene.

PO70

FACTORS INFLUENCING NIGHT SKY LIGHT POLLUTION IN GRASSLAND TOWNS

Ding, Y.[1,2] ,Su, X.[1,2] ,Hao, Z.[1,2], Han, Z[3] ,Cao, D.[1,2],Wei, W.[1,2]
[1] Architecture College, Inner Mongolia University of Technology; Inner Mongolia Key Laboratory of Green Building, CHINA, [2] Architecture College, Inner Mongolia University of Technology; Inner Mongolia Engineering Technology and Research Center for Green Buildings, CHINA,[3] Inner Mongolia Hengrui Energy Integrated Management Co., CHINA
dingarc@126.com

Abstract

In the areas of ecological preservation, human health, astronomical observation, and other areas, night sky light pollution has received a lot of attention. There are no quantitative description approaches for the changeable patterns of night sky light pollution. The exterior macro spatial form of night sky light pollution in grassland settlements is examined in this paper. The lighting status characteristics of grassland towns were quantitatively analyzed in this work, such as ground illumination, zenith brightness, urban night sky satellite photos.Then, the principal influencing factors are identified through statistical analysis, including urban lighting intensity, urban plane shape, and urban internal functional zoning. The aforementioned factors were then calculated through regression, and the result is a mathematical model were given which could describes the form of nighttime light pollution in grassland towns.The result serves as a guide for night sky light pollution assessment, management and development prediction.

Key words: Night sky light pollution; Grassland towns; Form; Prediction.

PO77

WHITE LED CHARACTERISTIC SPECTRUM OF VARIOUS CCT WITH OPTIMAL COLOUR FIDELITY INDEX AND COLOUR RENDERING INDEX

Yang, T.H., Chou, H.Y., Yu, Y.W., Sun, C.C.
Department of Optics and Photonics, National Central University, Chungli 32001, TAIWAN
thyang@dop.ncu.edu.tw

Abstract

1. Motivation

Light-emitting diodes (LEDs) have already become the dominant light source among all the existing ones. Besides, the standard light sources for the measurement and the calibration of the radiometry and the photometry are also of great necessity in utilizing the LED light sources. Therefore, the spectral properties of the LEDs are very essential subject for the applications. Especially, how to standardize the spectrum of the LEDs becomes the most urgent subject for the time being.

Generally, the most popular pc-WLEDs contain the blue dies covered by phosphor layers to emit white light of wide CCT (correlated colour temperature) range with acceptable CRI (colour rendering index). However, the composition of the LED spectra is complicated and not well quantitatively clarified yet so far. For the most common LED light sources, it consists of a blue LED die and the yellow YAG phosphor layer. In principle, there are at least two different essential mechanisms for the white light emission spectra. One is the generation-recombination of the electron-hole pairs in the blue LED die. Currently, the practical LED spectra have been successfully modelized by a simple four-parameters function. The other mechanism is the wavelength conversion effect in the phosphors. Indeed, the quantum single configurational coordinate model (QSCCM) proposes the Gaussian spectral function for the emission spectrum of any transition. Under such a circumstance, we already have enough information about LED illuminants for their spectral characteristics. Under such a circumstance, a calculation procedure similar to that for the CIE Daylight illuminants, therefore, can be setup for any pc-WLED spectra under various CCTs. Furthermore, we are easily to feature some certain characteristic WLED spectra according to having optimal CRI or having optimal colour fidelity index (CFI), and to make comparison between these two series of optimal WLED spectra.

2. Methods

To find the optimal LED spectra, we take two steps of analysis to approach the goal. The first step is to find an empirical function to lineate the LED emission spectrum with as few characteristic parameters as possible. As compared with a large amount of real LED spectra, the empirical spectra function is then confirmed. According to the existing reports, there are two candidates of the spectral functions for the blue LED dies. One is the sum of two Gaussian functions with 6 characteristic parameters, and the other is the asymmetric Gaussian-like function with only 4 characteristic parameters. For the sake of the convenience and the accuracy both, we prefer to the latter one with lesser parameters but still providing with enough accuracy.

Besides, based on the QSCCM suggestion, the suggested Gaussian spectral function for the phosphors is in term of the frequency rather than the wavelength of the light. We convert the QSCCM Gaussian spectral function into the alternative function form in term of the wavelength instead. Fortunately, it is found that the re-absorption and the re-emission phenomena also obey the behaviour predicted by the alternative spectral function form. For the emission from the YAG phosphors, we need two individual Gaussian spectral functions for two sub-bands corresponded to the $^2T_{g2} - {}^2F_{7/2}$ and $^2T_{g2} - {}^2F_{5/2}$ transitions, which are of two sets of 3 characteristic parameters.

In such a way, we now have a general spectral function with 10 characteristic parameters to precisely describe the full emission spectrum of a LED light source with very high accuracy. Among them, there are 3 characteristic parameters for the peak wavelengths, 4 characteristic parameters for the spectral bandwidths, and 3 characteristic parameters for the relative radiometric strengths. It is found that this characteristic WLED spectrum function is well approached to any one practically measured LED spectrum with very high accuracy.

The second step is the optimization process. Under any specified CCT condition and as normalized to the unit light power, the 3 characteristic parameters for the relative radiometric strengths are thus determined. Then, the rest 7 characteristic parameters are further figured out by the global optimization exploration. Finally, the optimal LED spectrum can be obtained. The details of the merit function might depend on the application requests. For example, the maximal CRI, the highest optic efficiency and so on. Here, we take the maximal CRI and the maximal CFI as the goal of all throughout optimizations.

3. Results

After the comparison with more than 1,000 various LED spectra collected from different manufacturers, our spectral model for the white LED light sources works very well. Furthermore, it does not only work very well for the blue LED with yellow phosphor, but also even for the RGB LED combo, the UV LED with RGB phosphors, the B/R LEDs with green phosphor, etc.

For simplicity, we optimize the case of the blue LED die with yellow phosphors only. By the optimization evaluation, the corresponding characteristic parameters are found and the optimal LED spectra for the maximal CRI and the maximal CFI are thus obtained of CCTs from 2,500K to 25,000K in steps of 500K, individually.

Furthermore, the relations among all the characteristic parameters for the optimal LED spectra and the corresponding CCT are also presented. Finally, a standard process is successfully constructed for calculating the white LED spectrum with maximal CRI and with maximal CFI under any specific CCT, which the process is very similar to the CIE Daylight Illuminant calculation. Some comparison between the optimal WLED spectrum with maximal CRI and with maximal CFI will be also presented.

4. Conclusions

In this work, we have successfully obtained the optimal LED spectra for the maximal CRI and for the maximal CFI of various CCTs, respectively. Similar to CIE Daylight Illuminants, we then conclude a calculation procedure for the spectral distribution of typical WLED in terms of any given CCT. It can easily apply for the standard LED sources in measurement and in the calibration of the radiometry and of the photometry. This work is believed to be a solid basis for establishing the reference LED illuminants.

PO79

A FIRST APPROACH TO A PREDICTIVE MODEL OF THE SKY SPECTRAL POWER DISTRIBUTION IN THE MEDITERRANEAN AREA

Aguilar-Carrasco, M.T.[1]; Acosta, I.[1]; Domínguez-Amarillo, S.[1]
[1] Instituto Universitario de Arquitectura y Ciencias de la Construcción, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, 41014 Sevilla, SPAIN
macarrasco@us.es

Abstract

1. Motivation, specific objective

The use of daylight inside buildings has always been a concern due to its impact on the users' health and comfort. Thus, natural light is the subject of study of much research and daylighting simulations play an essential role in this. On this matter, the definition of the sky luminance distribution under different situations becomes crucial. For this purpose, the International Commission on Illumination (CIE) establishes 15 different sky models to determine these sky luminance distributions. These daylighting simulations allow the calculation of metrics related to the lighting level such as Illuminance or Daylight Autonomy (DA), all of them mainly related to the visual comfort. However, light does not only affect human vision but also health due to its great effect on circadian rhythms, endogenous cycles responsible for several human body's functions. To assess the impact of light on the circadian system different metrics have been developed, such as the Circadian Stimulus (CS) or the Melanopic/Photopic ratio (M/P). The main two variables that influence this calculation are the illuminance levels and the Spectral Power Distribution (SPD) of the light source. In this sense, it is essential to know not only the sky luminance distribution but also the SPD. The CIE establishes the standard illuminant series D, a theoretical source representative of daylight with an SPD. Each of these standard illuminants corresponds to different sky types such as clear, intermediate, or overcast. Nevertheless, using, as an example, a CIE D65 as a representation of a clear sky does not correspond to reality. Under the same sky conditions, different SPD are obtained depending on the location, solar position, or orientation.

Therefore, the main objective is to perform a first approach for defining a predictive model of the sky spectrum to determine the SPD as a function of the sky type, solar position, location and orientation. This first approach is based on documentary research on the characterization of different sky types throughout the year in a specific location. For this, several measurements that allow this characterization are taken during the four seasons of the year. With these data, the sky spectrums are defined depending on the sky type and the different parameters influencing the relative luminance such as solar position or orientation.

2. Methods

To achieve this objective, the following methodology is developed and applied in a case study of the Mediterranean area. Firstly, a series of measurements are carried out for the sky characterization. The parameters considered are the luminance in the zenith and horizontal and vertical illuminance and SPD in the four orientations. The measures are carried out in the roof of a building located in Seville (Spain), with latitude of 37º 24' 15'' and a longitude of 5º 58' 50''. The measurement campaign is developed out for fifteen days at the winter and summer solstice and the equinoxes from sunrise to sunset in hour and a half time periods. The correlation between the local time at which the measures are taken with the solar time and the sun position – azimuth and solar altitude – is made.

Once the measurements are taken, the type of sky for each measurement is determined since those that are not CIE1, CIE7 or CIE12 must be discarded. To determine the type of sky,

equations developed by Kittler are used. With the measured correlated colour temperature (CCT) of the sky, knowing the spectrum of D65 and using the radiation intensity distribution curves for a blackbody obtained from the Planck Equation, the spectrum of the sky of any colour temperature is deduced.

3. Results

Once the measurements are carried out and the sky types are determined –CIE1, CIE7, and CIE12–, the average sky CCT–deduced from the measured spectra–is calculated every hour and a half, from sunrise to sunset. Thus, the average CCT is obtained in each orientation at the different sun positions throughout the day and therefore also the SPD.

With these results obtained a first analysis is made. Under an overcast sky —CIE1– the CCT remains almost constant regardless of season, solar position, and orientation. Only minor variations are noticeable at the beginning of the day, with sunrise. In contrast to this, clear and intermediate skies do show differences depending on the boundary conditions. In the north, a clear sky always has a higher color temperature than an intermediate one, although this difference between both varies depending on the season of the year and the sun position. However, in the south both skies show a similar performance throughout the day, reaching similar color temperatures with different sun positions. In this case the difference can be seen between the different seasons of the year, as these color temperatures are higher in winter than in summer. To the east and west the tendency of both skies –CIE7 and CIE12– throughout the day is similar, warmer in the mornings and colder in the afternoons to the east and backwards to the west, colder in the mornings and warmer at the end of the day, mainly due to the sun position.

4. Conclusions

With this methodology developed and applied to the case study of Seville, it has been possible to establish the different sky SPD depending on the relative luminance and sky type. These spectrums can be used in the calculation of the different metrics related with circadian rhythms to gain a more precise understanding of the natural light effect on people's health. Even so, this is a first approach to a future predictive model of sky SPD, so it has certain limitations. In future research, the number of measurements will be increased, achieving greater precision in the definition of the spectrum, and the number of sky types or locations can also be increased.

PO82

THE UGR CORRECTION FACTOR: A CASE STUDY

Audenaert, J.[1], Bauwens, E.[1], Leloup, F.B.[1]
[1] KU Leuven / Department of Electrical Engineering (ESAT), Gent, BELGIUM
Jan.Audenaert@kuleuven.be

Abstract

1. Motivation, specific objective

Glare is one of the key aspects of lighting that has gained importance with the implementation of LEDs in all aspects of lighting. Standards like EN 12464-1:2021 (Lighting of indoor work places) are there to ensure that people can perform their visual tasks in an efficient and accurate manner, without being disturbed by potentially disruptive effects of glare.

The Unified Glare Rating (UGR, CIE 117-1995) is a metric used to quantify the level of discomfort glare for indoor light sources and luminaires. From the luminous intensity distribution (LID) and the physical dimensions of the light emitting surface of a light source, the UGR can be calculated and reported in a so-called UGR table. This table lists the different UGR values for a range of standard installation geometries and room sizes.

In practice however, the dimensions of the light emitting surface used for the calculation of UGR are often a point of discussion. In fact, these dimensions have a major impact on the UGR values and can be misused – intentionally or unintentionally - to artificially lower the UGR value below the thresholds specified in the relevant standards. In 2019 CIE published a technical report (CIE 232:2019) proposing a correction factor to be added when determining the UGR. This correction factor is calculated from a set of luminance images captured at specific, predefined viewing angles with respect to the luminaire. Depending on the resolution of the imaging luminance measurement device (ILMD), the luminance images are processed with a Gaussian filter to obtain a resolution of 12 mm / pixel at the luminous surface. Next, based on a threshold luminance value of 500 cd/m2 the dimensions of the effective area of the light emitting surface which contributes to the level of glare, are determined.

In this case study, it is investigated if this correction provides a solution to the discussion of the appropriate dimensions to be used in the calculation of UGR, in order to have a realistic representation of the glare level of the light source.

2. Methods

A standard, non-uniform office luminaire with 2 distinct LED arrays was selected for the practical study. The LID of this luminaire was measured with a near-field goniophotometer (NFG) setup. In addition, high dynamic range luminance images at 4 different angles, as specified in CIE 232:2019, were measured with the ILMD of the NFG. From these measurements and based on 3 different surface areas that could be referred to as being the light-emitting surface, the standard UGR was calculated. Dialux simulations were performed to check the calculated differences in UGR. Likewise, the corrected UGR was calculated taking into account the luminance threshold to determine the effective luminous area of the luminaire. Finally, a simulated dataset with high peak luminance was created based on the actual measurement data to assess the ability of the corrected UGR method to identify this dataset as highly glare.

3. Results

Based on the various luminous parts that could possibly be defined as the effective light-emitting surface of the luminaire, the average uncorrected UGR values of the calculated UGR

tables range from 11 over 16 to 23 units. Dialux simulations in a room with dimensions 6.4m x 12.8m x 2.8m (room size 4H 8H), in which the luminaire with modified light-emitting surface was applied according to the 3 predefined alternatives, generally confirm these results and report maximum UGR values of 13, 18 and 25 units, respectively. Applying the calculated correction factor from the set of captured luminance images leads to a correction of the UGR value in 2 of the 3 test cases, changing the uncorrected UGR values of 11 to 16 units, and of 23 to 16 units, respectively. The uncorrected UGR value of the third alternative is not significantly changed, indicating that the luminous area taken into account for the calculation of UGR in this third alternative approximately corresponds to the luminous area determined from the threshold luminance value applied for the correction.

The practical results in this case study thus demonstrate that the proposed uniformity correction factor results in UGR values that are independent of luminaire dimensions, i.e., the correction factor indeed identifies the luminous surface area that effectively contributes to glare.

However, when introducing exceptionally high luminance values within the contributing region while keeping the total luminance value of the luminaire the same, no increased glare rating is found when implementing the correction factor.

4. Conclusions

The corrected UGR puts a stop to all discussions surrounding the UGR calculations based on luminous surface dimensions. It proves therefore to be a major step forward in obtaining a more objective UGR metric which can be compared directly between different luminaires and manufacturers.

In order for the corrected UGR to also be able to identify high peak luminance sources as high glare sources, further research and modifications, for instance based on the theory of receptive fields, are needed.

PO84

INTERCOMPARISON OF BIDIRECTIONAL REFLECTANCE DISTRIBUTION FUNCTION MEASUREMENTS AT IN- AND OUT-OF-PLANE GEOMETRIES

Basic, N.[1], Molloy, E.[2], Koo, A.[2], Ferrero, A.[3], Santafé Gabarda, P.[3], Gevaux, L.[4], Porrovecchio, G.[5], Schirmacher, A.[6], Šmíd, M.[5], Blattner, P.[1], Hauer, K.-O.[6], Quast, T.[6], Campos, J.[3], Obein, G.[4]
[1] Eidgenössisches Institut für Metrologie METAS, Bern-Wabern, SWITZERLAND, [2] MSL Measurement Standards Laboratory of NZ, Callaghan Innovation, Lower Hutt, NEW ZEALAND, [3] Instituto de Óptica "Daza de Valdés", Consejo Superior de Investigaciones Científicas, Madrid, SPAIN, [4] LNE-CNAM (EA 2367), La Plaine St Denis, FRANCE, [5] Cesky Metrologicky Institut (CMI), Brno, CZECH REPUBLIC, [6] Physikalisch-Technische Bundesanstalt, Braunschweig, GERMANY
nina.basic@metas.ch

Abstract

1. Motivation, specific objective

Requests for quantitative measurements of visual appearance have substantially increased in recent years because of their value in industry as customers place increasing importance on the aesthetic appeal of merchandise. More and more complex materials developed by industry require measurements of the so-called bidirectional reflectance distribution function (BRDF), where one measures how a material diffusely reflects light when illuminated from a given direction. These measurements play an important role in optical metrology applications and aerospace projects, as well as in many industries, such as automotive, paper, textile, colour, cosmetics, 3D printing, high-technology, and virtual reality.

Bidirectional reflectance scales are currently not included in any key comparison arranged by the Consultative Committee of Photometry and Radiometry (CCPR) of the International Committee for Weights and Measures (CIPM). A few bilateral comparisons were conducted, however, they focused only on classical in-plane geometries. This study presents a multilateral scale comparison of BRDF measurements performed between four national metrology institutes and two designated institutes.

2. Methods

The measurement comparison included three achromatic samples: two sintered Polytetrafluoroethylene (PTFE) samples and one satin sample. The two PTFE samples have nominal reflectance values of 99% and 50%. The satin sample was produced specifically for the measurement comparison and consists of white acrylic paint spread by pulverization on a glass substrate to provide good support and ensure the sample's flatness and stability. In contrast to the two PTFE samples, the satin sample is not a quasi-Lambertian sample: it has a nominal gloss value of 20 GU at 60° measurement geometry.

Each participant of this round robin comparison measured the samples in five measurement geometries: three in-plane [(0°, 0°) : (45°, 180°), (45°, 0°) : (0°, 0°), (45°, 0°) : (60°, 180°)] and two out-of-plane geometries [(45°, 0°) : (45°, 90°), (45°, 0°) : (50.1°, 146.6°)]. The measurand for the comparison is the BRDF of a 10 mm diameter area in the centre of each sample in the above defined five geometries for unpolarized light of 550 nm with a 5 nm bandwidth. The parameters were carefully selected in order to avoid any polarization bias or speckle influence.

The evaluation of the measurement comparison follows the Guidelines for CCPR Key Comparison Report Preparation. The reference value is computed using the Mandel-Paule method, where an interlaboratory uncertainty component is added to all participants' uncertainties until the data is regarded consistent. The iterative process is executed for every sample and every geometry separately.

3. Results

The selection of the combination of samples and measurement geometries allows us to identify any systematic errors in the measurements, especially concerning the alignment of angles and sample alignment. The (45°, 0°) : (0°, 0°) and (0°, 0°) : (45°, 180°) geometries provide a baseline for the diffuse part, while the rest of the geometries show the variation in the BRDF value and are, therefore, more susceptible to any alignment error.

The possible non-isotropy of the samples was tested by calculating the compatibility index between (45°, 0°) : (0°, 0°) and (0°, 0°) : (45°, 180°) geometries for every participant separately. The calculated indices show very good compatibility between the two geometries, meaning that the samples are isotropic.

The results demonstrated some discrepancies between the measurement scales. A non-negligible contribution of interlaboratory uncertainty was estimated to achieve consistency. One possible explanation could be underestimation of the uncertainties. These uncertainty contributions should be revised by all participants. In particular, it might be important to quantify the uncertainty due to non-negligible solid angles at those geometries for which the angular gradient of the BRDF can be high enough to affect the measurement.

4. Conclusions

The study presents the results of a multilateral measurement comparison of BRDF in three in-plane geometries, and for the first time, also in two out-of-plane geometries. The comparison of the measured values presents slight inconsistencies at some geometries, most likely due to the underestimation of measurement uncertainties. This underestimation was revealed and indirectly quantified using the Mandel-Paule method, which provides the interlaboratory uncertainty. The results from the presented comparison allow the present state of the BRDF scale realization to be evaluated, not only for classical in-plane geometries, but also for out-of-plane geometries.

PO88

A NEW BRDF MODEL FOR IN-SITU OPTICAL AND THERMICAL MATERIAL CHARACTERIZATION

Bouillot, E., Labayrade, R., **Legrand, B**
Ecole Nationale des Travaux Publics de l'Etat (ENTPE), Vaulx-en-Velin, FRANCE
emile.bouillot@entpe.fr

Abstract

1. Motivation and objective

The optical and thermal characterization of materials (*i.e.* radiometric characterization in the visible and infrared ranges) is an important way to reduce energy consumption in buildings. Characterizing the properties of building surfaces *in situ* prior to rehabilitation will make possible the selection of rehabilitation materials that achieve the best compromise between summer and winter comfort, while significantly reducing energy consumption.

Thermal and optical properties of materials can be described using the Bidirectional Scattering Distribution Function (BSDF), which defines the proportion of energy reflected (BRDF) or transmitted (BTDF) compared to the incident energy. BRDF is a high dimensionality physical quantity that is memory consuming and time expensive to measure as it contains spectral information for all incident and observation angles. BRDF analytical models have been proposed in the literature and while capturing the average material behavior, sometimes present inaccuracies for some parts of the BRDF, especially in the diffuse lobes which yet are involved in most of the incoming energy reflection or transmission. To develop a new method for measuring *in-situ* BRDF, we propose a new BRDF model suited to building materials in particular.

2. Approach

Although analytical BRDF models have been investigated for a long time, most of them present a constant diffuse part. However, BRDF measurements of various kind of materials such as building materials (*e.g.* paints, concrete, plastics) show the diffuse lobe varies as a function of both the incoming and outcoming light angles. Since most of the energy reflected by a material comes from the diffuse part, improving its modelling would allow a more accurate approximation of the actual material behavior, and thus more relevant strategies for building rehabilitation. In addition to the diffuse lobe, the new BRDF model we propose include glossy and intermediate parts. Their formulations are data-driven, in the way that the parameters of the model have been derived from tabulated BRDF measurements of actual materials using a goniophotometer.

A data-driven model involves i) measuring the BRDF of real materials, ii) formulating the analytical model itself depending on parameters to identify, and iii) fitting the model with respect to the data for a particular material. We chose to develop an isotropic model because most building materials can be considered isotropic with little loss in generality. As a result of this choice, the measurements with the goniophotometer were simplified to slices of BRDF, *i.e.* depending only on the incoming and outcoming zenith angles.

The measurements were performed for nine incident angles (10, 20, …, 70, 80, 85°), and for each incident angle, for viewing angles with a spacing of 10° for the diffuse part, and for every degree around the specular direction (between -10° and 10° around).

3. Proposed model

The analytical model is divided into three parts: a diffuse part, a glossy part and an intermediate part modelling a slice of BRDF. These three parts have been considered from the shape of the measured slices where a non-trivial transition between the glossy and the diffuse part could be noticed.

Diffuse and glossy parts are normalized and then modelled as polynomial functions (degrees 2 and 3); the normalization factors are modelled as an exponential for the glossy lobe and a power for the diffuse lobe. The transition lobe is obtained as an interpolation between glossy and diffuse with constraints on derivates (the introduction of this third part leads to the addition of another parameter related to the angle from which the transition part begins).

The proposed model relies on 10 to 12 parameters and allow to estimate the BRDF for both in plane and out of plane directions.

4. Model accuracy

We have tested our model on various BRDFs measured by our goniophotometer, which were all related to paints. We calculated the model error for both the diffuse and glossy parts and compared our results to other models from the literature, namely Ward (2014), Brady (2014), and Ashikmin (2000). Our results were superior to those in the literature for the diffuse part because most of the diffuse parts in the literature are constant, whereas our model employs more parameters to describe the diffuse part. For example, the relative error for five paints was 74% for our model, 172% for Ward, 141% for Brady, and 1027% for Ashikmin.

For the glossy part, with an equal number of parameters, our model yielded less accurate results than Brady and Ward, but similar results to the others. For example, the relative error for five paints was 24% for our model, 16% for Ward, 9% for Brady, and 40% for Ashikmin.

5. Perspectives

In view of the results obtained, we could mix our model with others from literature, using use the diffuse part of our model and the glossy part of Ward or Brady. This would allow to obtain better accuracy overall. Then, we will investigate how to use this model for *in-situ* estimation of radiometric material behavior in the visible and infrared ranges.

Currently, to measure a BRDF, we need to obtain a sample of the material and perform the measurement with a goniophotometer in a laboratory. However, this process is slow and there is a risk of lack of representativity of actual materials which can be dirty or aged. The model will be used for *in-situ* BRDF estimation, along with a camera that captures a set of BRDF samples from which fitting can be performed. In future work, we aim to extend the estimation to the spectral domain, still using a single camera, but relying on a neural network. This neural network will be trained from a database consisting of "image of the material / BRDF parameters of the material from our model (visible and infrared spectrum)" pairs. With this approach, radiometric characterization in the visible and infrared ranges from a single picture will be evaluated.

PO90

CURVE FITTINGS OF SPECTRAL RADIANCES OF R, G, AND B MINI-LED SAMPLES MEASURED BY A 2D-SPECTRORADIOMETER

Hsu, S-W.[1], **Chen, C-H.[1,2]**, Hung, S-T.[1,3]
[1]Center for Measurement Standards, Industrial Technology Research Institute, Hsinchu, TAIWAN, [2]Department of Optics and Photonics, National Central University, Taoyuan, TAIWAN,
[3]Graduate Institute of Electro-Optical Engineering, NTUST, TAIWAN
ChrisCHChen@itri.org.tw

Abstract

1. Objective

This work studies the properties of spectral radiances of R, G, and B mini-LED array samples by experiments with a 2D-spectroradiometer and analyzations with curve scaling and modeling methods. The parameters for curve scaling are the peak radiance, frequency at peak, and full widths at half maximum. The following modeling of the scaled curves of different materials is based on an equation with two parameters related to the low- and high-energy values of the LED samples.

2. Methods

A Topcon SR-5000 2D-spectroradiometer was used to measure the 2D distribution of spectral radiance for each chip. Samples for the measurements are the R, G, and B mini-LED arrays, which were prepared by soldering commercial SMD chips on PCB boards. The current applied to the LED arrays is ranged from 0.1 to 4 mA per chip by a Keithley 2400 source meter.

The measured 2D distribution of spectral radiances of each chip was averaged to study the variance of physical properties of these mini-LEDs with material, individual chips, and applied current. To have more physics-based background, the spectral radiances (L) were converted to frequency (f) (and therefore energy) dependent. The peak radiances (L_p), frequencies at peak (f_p), and full widths at half maximum (FWHM, Δ) were calculated from the spectral radiances.

3. Results

The peak radiances are nearly proportional to the applied current for all kinds of measured mini-LED chips, which is confirmed with experiments on most LEDs. The FWHM of the R, G, and B mini-LEDs are between 11.7~13.7, 29.4~32.9, and 21.8~25.4 nm, respectively, and are linearly dependent on the applied current. The frequencies at the peak of the R, G, and B mini-LEDs are between 478.0~476.0, 570.4~576.6, and 667.4~671.0 THz, respectively.

The spectral radiance curves can be scaled to L/L_p versus $\kappa=(f\text{-}f\text{p})/\Delta$ for different materials of mini-LEDs. Except for some small humps, these scaled curves are almost overlapping and independent on the individual chip and applied current. Further modeling of these scaled curves was performed with a two-parameters model of $(a_1+a_2)/[a_1 \cdot \exp(a_2\kappa)+a_1 \cdot \exp(-a_2\kappa)]$. The parameters ($a_1$, a_2) of the R, G, and B min-LED are (1.76, 4.11), (3.73, 1.99), and (2.50, 2.63), respectively. Compared with the theoretical model, Δ/a_1 and Δ/a_2 are respectively proportional kT_c and another energy term α, where the parameter T_c is the carrier temperature of the LED. These interesting features may provide clues for the research on the physics of mini- or micro-LEDs.

4. Conclusions

The measurements of 2D-distribution spectral radiances of the R, G, and B mini-LED arrays based on a 2D spectroradiometer are performed in this study. The results of experiments can be empirically analyzed by simple processes with a few parameters that are related to the intrinsic properties of mini-LED.

PO91

MEASURING THE VISUAL ENVIRONMENT OF CHILDREN AND YOUNG PEOPLE AT RISK OF MYOPIA: A SCOPING REVIEW

Dahlmann-Noor, A.[1], Bokre, D. [1], Khazova, M.[2], Price, L.[2]
[1] NIHR Moorfields Biomedical Research Centre, London, UK, [2] UK Health Security Agency, London, UK
annegret.dahlmann-noor@nhs.net

Abstract

1. Motivation, specific objective

It is widely recognised that the visual environment of children and young people with myopia differs from that of non-myopic children. It is likely that urbanisation and reduction of time spent outdoors/exposure to bright light have a causal impact on myopia onset and progression, and it is possible that differences in spectral composition of indoor and outdoor light contribute as well.

Studies exploring the visual environment have used different technologies, and they have been conducted in different countries and in different settings. We plan to develop a programme of work to optimise the visual environment of children in the UK, with the ultimate aim of delaying myopia onset and slowing progression. To inform this work, we are carrying out a scoping review of the literature. Specific objectives are

- to describe which measurement technologies have been used to measure the visual environment of children (parameters related to light exposure and near-work), both at individual level and for clusters of children, for example schools
- to identify gaps in knowledge that could be addressed by established and novel measurements techniques and by combining individual and cluster-level measurements

2. Methods

An experienced search strategist developed and carried out the literature search, using search terms relevant to myopia, indoor and outdoor lighting and activities, green spaces, housing, and nearwork. On 13/07/2022 we carried out an initial search of one database (Medline); further databases will be searched in March 2023.

We included papers which used objective measurements of light and/or near-work-related parameters, published in peer-reviewed journals, written in English, involving children and young people age 3 to less than 19 years. We excluded studies which report measurements taken in clinical settings only. We used an abstract screening tool to ensure consistency. Two authors screened all titles and abstracts, discussed and resolved disagreements within the software package Covidence.

After full-text review and finalisation of inclusion, we extracted data on year of publication, study location (country), measurement technologies used, interventions (if any), whether measurements were obtained at the level of the individual or the overall environment, which aspects of light and near-work were measured, indoor/outdoor location, settings of measurements (school, home, leisure), and, where appropriate, number of participants and mean age.

3. Results

The initial search revealed 4,246 publications; 3 duplicates were removed. Title and abstract review eliminated 3,894 studies. Of 348 full-texts reviewed, 23 were included in the review.

The date of publication ranged from 2003 to 2022. Thirteen publications used individual-level measurement technologies to determine light- and/or near-work related outcomes; 10 acquired environmental measurements without human participants, but correlated these with findings from cohorts of children with or without myopia. No study combined measurements obtained for the environment of groups of children with measurements of the individual exposure of children.

Individual-level measurements were reported for children in Australia, China, Israel, Singapore,Taiwan and USA. Environmental data were reported for Australia, Brazil, China, Finland, Hong Kong, India, Iran, Israel, Japan, Korea, Netherlands, Oman, Singapore, South Africa, Spain and the UK.

Individual-level measurements included light intensity and spectral composition, measured using wearable devices, mounted onto spectacle frames, worn as pendants, or worn on the wrist. Duration spent at light intensity greater than 1,000 lux was assumed to be time spent outdoors. Four studies measured near-working distance and duration using spectacle-mounted infrared sensors. Wearable measurement devices collected data during time at school, home, and leisure.

Environmental studies not acquiring individual-level light measurements included five studies using lux meters (illuminometers) measuring light intensity at schools, indoors or both indoors and outdoors, 1 study measuring dioptric volume in children’s study desk at home, three studies using satellite data on greenness (Normalized Difference Vegetation Index) around children’s schools and homes, and one study using QGIS software to measure the distance from newly created physical activity spaces to children’s homes.

Where data from children were reported, the mean age of participants ranged from 4.87 to 14.6 years.

Core findings of included studies are that agreement between parental diaries and luxmeters as measures of time spent outdoors is poor to fair.

Children with myopia have both lower mean daily light exposur and shorter daily exposures to bright light (>1,000 lux) than non-myopic children. Axial elongation correlates with mean daily light exposure and with time spent outdoors.

Online schooling is associated with a reduction in time spent outdoors. During the COVID-19 pandemic, children spent less time outdoors and more time on electronic devices.

When time spent outdoors is used as an intervention, the intervention group does spend more time outdoors than the control group, and there is a slight reduction of axial elongation over 12 months.

Children with myopia spend more time on near- and intermediate-distance work than non-myopic children, and use a shorter working distance for near-work than non-myopic children at least some of the time.

There is both a correlation and an interaction between light intensity and working distance in terms of their impact on myopia.

Illuminance varies widely in different locations in classrooms, from just over 300 to over 3,000 lux. Axial elongation is less in children taught in classrooms with high daylight factor than those in classrooms with low daylight factor (ratio of indoor to outdoor illuminance).

Optimising lighting in classrooms is associated with a reduction in new-onset of myopia (incidence) and reduced progression. Glass classrooms are an architectural alternative to increase classroom illuminance; a pilot increased illuminance 5-fold.

Increased exposure to green space at home, school and during commuting is associated with less need for spectacles. Higher levels of greenness around thehome is associated with a reduction in risk of myopia. However, introduction of new physical activity spaces is not necessarily associated with a local decrease in children’s axial elongation.

4. Conclusions

Gaps in knowledge include illuminance in classrooms in schools, outdoor light exposure at school, home and leisure, as well as data on near-work habits of children and young people in the UK.

PO94

URBAN ARTIFICIAL LIGHT SPECTRUM DISTRIBUTION MODE OVER NIGHT SKY

Su, X [1,2], Ding, Y.[1,2], Hao Z.[1,2]
[1] Architecture College, Inner Mongolia University of Technology; Inner Mongolia Key Laboratory of Green Building, CHINA, [2] Architecture College, Inner Mongolia University of Technology; Inner Mongolia Engineering Technology and Research Center for Green Buildings, CHINA
sxmarc@126.com

Abstract

Spectrum distribution characteristics are important factors to determine the level of light pollution over urban night sky. Nevertheless, to describe the spectrum distribution character which belongs to a wide range of artificial light over urban are difficult. To deal with the problem, we had developed a light spectrum distribution mode, which is suitable for wide area light environment. In line with effort, the ground based urban lighting spectral were test to reveal the characteristics of radiation intensity and spectrum distribution. Combined with literature analysis result and initial field test date of Inner Mongolia, China, the paper presents the atmospheric absorption coefficient effect of on urban artificial light spectrum distribution. Whilst, light pollution spectral distribution date information from satellite image were compared with ground-based zenith light observations date. The comparison results were applied to describe spectral characteristics near the exterior boundary of urban sky light pollution. Based on the information, same regression analysis methods were used to develop a spectrum distribution mode which suite for deferent altitude over urban. The final result will serve as a platform for future researchers to make urban lighting design and dark sky protection better.

Key words: Light pollution; Sky glow; Artificial lighting; Spectral characteristics.

PO96

AN ASSESSMENT OF TWENTY YEARS OF TRAP DETECTOR ABSOLUTE RESPONSIVITY MEASUREMENTS

Dury, M.R.[1]
[1] National Physical Laboratory, Teddington, UK
martin.dury@npl.co.uk

Abstract

The absolute spectral responsivities of three-element trap detectors calibrated against a primary standard cryogenic radiometer over a twenty-year period are assessed at key wavelengths. As expected, the absolute spectral responsivities decrease over time. The ageing rate increases as the wavelength decreases, but the decrease in absolute spectral responsivity at shorter wavelengths is reasonably linear, meaning their future performance is relatively easy to predict. At longer wavelengths the detectors are far less sensitive to ageing and monitoring changes here may be good indicator of the general health of the whole trap detector, as well as the quality of the measurement. Potential causes of changes in the absolute spectral responsivity of trap detectors are also discussed.

1. Motivation, specific objective

This study was conducted with a view to potentially modelling future performance and to develop a greater understanding of the effect of long-term ageing on the responsivity of three-element silicon trap detectors. Absolute spectral responsivity data from the measurement records of three trap detectors calibrated against a primary standard cryogenic radiometer were analysed. The records cover a time-period of more than twenty years.

2. Method

For each of the absolute spectral responsivity calibration measurements, the three-element silicon trap detectors were calibrated against a primary standard cryogenic radiometer at a series of krypton ion laser wavelengths.

The laser beam was uniform with a diameter of approximately 4 mm. The beam's power was approximately 0.5 mW and was stabilised to better than 1 part in 10^4.

The laser beam was directed into the cryogenic radiometer cavity. The three-element silicon trap detectors were installed onto a motorised stage that allowed them to be moved into and out of the beam. Each detector was aligned perpendicular to the incident beam, such that the signal on each detector was maximised. The calibration of the trap detectors was performed almost annually.

3. Results

At ultraviolet wavelengths, relatively large linear decreases in absolute responsivity of approximately 3% were exhibited by the three trap detectors over the twenty-year period of assessment. The behaviour is sufficiently linear to predict, with a high degree of confidence, the future performance of an individual detector. At near-infrared (NIR) wavelengths, the decrease in absolute responsivity was many times smaller at around 0.1% over the twenty years. In the NIR, all the detectors exhibited non-linear changes in their absolute responsivities over the first few years after manufacture, however over the longer-term performance may be more predictable.

4. Conclusions

As expected from silicon-based detectors, all three detectors under assessment exhibited a decrease in absolute spectral responsivity at all wavelengths over the twenty-year period of assessment. Factors in the decrease may include changes in the SiO_2 layer at the front surface of the detectors, as well as potential changes in the internal alignment of the detectors due to the gradual deterioration in the strength of the adhesive used to attach the detector elements to the former. Over time, dust or other contaminants may settle on the detector elements reducing performance. Factors such as sensitivity to small changes in alignment may also have influenced the results, especially since several different scientists performed the measurements over this long time, leading to apparent changes in absolute responsivity at longer wavelengths, which are not visible at shorter wavelengths where other influences are dominant.

PO103

MODELLING THE SPECTRAL POWER DISTRIBUTION OF MONOCHROMATIC AND PHOSPHOR-CONVERTED POWER LEDS

Lipák, Gy. [1], Takács, D.[1] Hegedüs, J. [1], Hantos, G.[1]
[1] Budapest University of Technology and Economics, Faculty of Electrical Engineering and Informatics, Department of Electron Devices, Budapest, HUNGARY
hegedus.janos@vik.bme.hu

Abstract

1. Motivation, specific objective

It is particularly important to know the exact spectral power distribution of power LEDs during the design phase of any lighting applications, since several important and frequently used parameters can be derived from it, such as the radiant and luminous flux, the colour rendering index, the correlated colour temperature and many more. However, the spectral power distribution of LEDs strongly depends on the operating temperature and on the forward current.

If the accurate modeling of the spectral power distribution of an LED is critical (for example, in the case of public lighting or automotive applications), it may be necessary to know the behaviour of the LED depending on the environmental parameters. This is especially true in the case of complex modules, such as in case of white light sources based on colour mixing, where the environmental sensitivities of the applied individual LEDs or LED types are even different. The exploration of such relationships is a so-called multi-domain task, that is, the electrical, optical and thermal operation of the LED must be investigated at the same time.

Accurate modeling of the spectral power distribution of monochromatic and phosphor-converted white LEDs as a function of temperature, forward current, and in special cases even the elapsed operating time (that is, the aging of the LED) can become an extremely important and useful part of a circuit simulation multi-domain LED model, which serves as reliable and accurate input data for lighting design processes with an Industry 4.0 approach.

2. Methods

Full characterization of monochromatic and phosphor-converted power LEDs is possible using the so-called multi-domain measurement procedure. Multi-domain measurement of LEDs means that the semiconductor is examined in a complex manner covering all aspects that determine its operation in the electrical, thermal and optical domains. This is the so-called combined thermal and radiometric/photometric characterization. For encapsulated semiconductors, thermal characterization can be carried out, for example, with the help of thermal transient testing. During the measurement, the diode is allowed to warm up by driving it with the normal operating current, and in the case of light-emitting diodes, the optical parameters are measured after reaching a thermally stable state. After that, the current of the LED is turned off, thereby creating a dissipation jump at the input of the thermal system, i.e. on the LED chip. Hereafter, the forward voltage of the diode during its cooling transient can be measured with the so-called measuring current, a current significantly smaller than the normal operating current.

In order to measure the parameters of phosphor materials separately from the encapsulated LEDs, different methods may be applied. In the case of one of the methods we propose, we use a self-made phosphor + lens arrangement, which can be used to measure the exciting encapsulated blue LED and the phosphor arrangement separately. In the case of the other proposed method, the excitation light source and the phosphor layer are spatially separated (i.e. remote phosphor arrangement), which can be used to eliminate the thermal coupling between the main components. However, this arrangement does not provide information about the extraction efficiency of the powder lenses.

3. Results

In the final article to be submitted, the latest results of the LED spectral power distribution modelling work carried out at our institution will be described. During this, the standard and special measurement arrangements and the experiences gained during the tests will be presented. The mathematical models used for modelling and the accuracy of the model fits will be described. Modelling white LEDs converted with phosphors as the exciting blue source and the possibility of separate modelling of the phosphor layer will also be discussed.

4. Conclusions

Lifelike and accurate models are the most fundamental cornerstone of Industry 4.0 design processes. When modelling LED-based light sources, one of the most important output parameters is the spectral power distribution, since most radiometric and photometric parameters of LEDs can be calculated from it. However, the spectral power distribution also depends on the temperature of the LED chip, the forward current and the aging of the device, which is why its accurate characterization and modelling requires special measurement arrangements.

One of the important tasks of the international project work currently running at our institution is the definition, testing and validation of such measurement and modelling procedures, as well as the establishment and further development of the necessary circuit simulation multi-domain LED models.

PO113

SPECTRORADIOMETER CALIBRATION WITH AN UAV-BORNE LIGHT SOURCE

Ivanescu, L.[1,2], Marseille, C.[1], O'Neill, N.T.[1], Albert, J.[3]
[1] Département de Géomatique Appliquée, Université de Sherbrooke, Sherbrooke, CANADA
[2] Metrology Research Center, National Research Council Canada, Ottawa, CANADA
[3] Department of Physics and Astronomy, University of Victoria, Victoria, CANADA
Liviu.Ivanescu@usherbrooke.ca

Abstract

1. Motivation, specific objective

The goal of the Canadian Space Agency's "Flights for Precision Calibration for Dark Energy, Microwave Astronomy, and Atmospheric Physics" project (which is, in turn, part of the "Airborne Laser for Telescopic Atmospheric Interference Reduction" or ALTAIR project) is to investigate the feasibility of a satellite- and balloon-borne calibration light source. To this end, we employed an UAV (Unmanned Aerial Vehicle) in order to investigate the feasibility and the limitations of performing a spectroradiometer calibration using an airborne light source. With a speed of 0.25-0.5 m/s, at about 100 m altitude above ground, the UAV simulates the expected 25-50 m/s drift of a 10 km altitude radiosonde balloon. Beyond addressing the ALTAIR tracking objectives we also assessed the calibration challenges in acquiring the signal of such a close light source given its wind-driven, high frequency motion both along the observing direction and across the field of view.

2. Methods

We employed a Dr. Schulz & Partner starphotometer (a 400-1100 nm spectroradiometer, with a 0.3 mrad field of view, at the focus of an Alter M703, 7-inch telescope, on a Gemini Losmandy mount). This instrument is located on the roof of the SIRENE (Site interdisciplinaire de recherche en environnement extérieur) site at 315 m above sea level (located on a hill behind the Université de Sherbrooke in Sherbrooke, Quebec, Canada). We used a DJI Phantom 4 Pro UAV equipped with a custom RGB LED light source. The LED spectrum was measured with a StellarNet lab spectrometer. Starphotometer measurements were performed at four fixed UAV positions between 700 and 1500 m distance and at 115 m elevation, spanning a 5-10 degree elevation above the horizon (equivalent to a 0.9-0.2 airmass range). The LED light was always pointed towards the starphotometer in order to limit emission function errors.

3. Results

By extrapolating to zero-airmass a Langley linear regression on those four measurement points, we estimated the eventual measurement just in front of the instrument (otherwise impossible to measure). The (magnitude) difference between these retrievals and the LED StellarNet lab measurement provided the calibration spectrum (i.e. the optical throughput of the spectroradiometer-telescope system). The unexpectedly large slope of the Langley calibration (suggesting high aerosol load) is misleading, since this is equivalent with extrapolating the near-surface load to the entire atmosphere.

4. Conclusions

The telescope focus had to be adjusted for each UAV position because of the small UAV-source separation: this led to source acquisition challenges. The current mount was not fast enough to track the required source movement to simulate radiosonde drift (no mount is likely fast enough). Even fixed UAV positions proved to be challenging since they could be unstable even in weak wind conditions. Technical solutions based on adaptive optics are proposed for future real time tracking of the light source (as well as for focus adjustment). While the retrieved calibration spectrum is qualitatively similar to starlight spectra, the substantial difference may largely be attributable to flux losses induced by poor source targeting.

PO118

UNCERTAINTY EVALUATION OF HORTICULTURAL LEDs AND MONTE CARLO SIMULATION APPROACH

Kösemen, Z.A.[1], Yaran, Ş.[1], Akkan, Ç.K.[1], Nişancı, H.F.[2], Sperling, A.[3]
[1] TÜBİTAK UME, National Metrology Institute of Türkiye, Kocaeli, TÜRKİYE, [2] Kocaeli University, Kocaeli, TÜRKİYE, [3] Physikalisch-Technische Bundesanstalt,National Metrology Institute of Germany, Braunschweig, GERMANY
zuhal.kosemen@tubitak.gov.tr

Abstract

1. Motivation, specific objective

The utilization of Light Emitting Diode (LED) light sources has shown tremendous potential as an emerging technology, primarily due to their remarkable features including energy efficiency, prolonged lifespan, durability, availability in various sizes, and versatile applications in diverse areas. Notably, their employment in the agricultural sector has gained widespread momentum in recent times. Consequently, the characterization and calibration of these sources is of outstanding importance in this context.

This study aims to evaluate the uncertainty of Photosynthetic Radiation Flux and Photosynthetic Photon Flux parameters of horticultural LEDs from the spectral measurements.

2. Methods

In the fields of photometry and radiometry, spectral measurements play a crucial role in determining various parameters. The photometric parameters like total luminous flux, colour coordinates, photometer responsivity, spectral mismatch correction factor, etc. are attained by integrating spectral quantities. For horticultural lighting, photosynthetic parameters, subject to this study, are also obtained by integrating the spectral quantities.

In spectral measurements, uncertainties of parameters at each wavelength are typically assigned using the GUM uncertainty framework or Monte Carlo simulations. Uncertainties of the integrated quantities are also obtained by combining the uncertainties of the spectral quantities of all wavelengths in the related wavelength range.

Photosynthetic parameters, Photosynthetic Radiation Flux (PRF) and Photosynthetic Photon Flux (PPF), are calculated using spectral radiant flux in the wavelength range between 400 nm and 700 nm. In this wavelength range, in which the common plant species are sensitive, the photosynthesis process is carried out.

One of the spectral radiant flux measurement methods is carried out using an integrating sphere with a spectroradiometer. In this method, the LED light source for horticulture is compared with a reference spectral flux lamp which spectral radiant flux values are certificated. Then LED Light source's spectral radiant flux values are determined. Subsequently the PRF and PPF values are calculated.

The uncertainties of the PRF and PPF measurement results are calculated using the GUM uncertainty framework and Monte Carlo simulation. In addition, Monte Carlo simulation is used to determine the effect of the correlations between the individual uncertainty inputs and the correlation between the spectral measurement results at different wavelengths obtain.

3. Results

The uncertainty values of PRF and PPF were assigned using two different approaches. The results were validated with slight differences. The correlations between individual uncertainty inputs are obtained from Monte Carlo Simulation. Some inputs belonging to investigated parameters exhibit a strong correlation among them. Also, additional correlations were obtained between different wavelengths. The contributions of these correlations are unknown

and can not be calculated with the classical method. Therefore the contributions increase the uncertainty calculated with Monte Carlo.

4. Conclusions

The uncertainty values of PRF and PPF measurements are calculated using two approaches, a) Classical GUM approach (JCGM 100) with the assumption that all measurement data are completely uncorrelated, and b) Uncertainty estimation according to GUM Supplement 1 (JCGM 101) using Monte Carlo Simulation. The latter approach was also be employed to validate the calculated uncertainties. The uncertainties of PRF and PPF values were more accurately calculated with unknown correlations because the uncertainties obtained from Monte Carlo Simulation covered both uncorrelated contributions and unpredictable correlated contributions.

PO125

IMPACT OF DAYLIGHT CHANGES ON PSYCHOLOGICAL AND PHYSIOLOGICAL ASPECTS OF RESIDENTS IN AN APARTMENT BUILDING

Murayama, E.[1], Heo, J.[1], Kubo, H.[1] Yoshida, S.[1]
[1] Nara Women's University, Nara-shi, JAPAN
wae_murayama@cc.nara-wu.ac.jp

Abstract

1. Motivation

The right to sunlight is protected under detailed regulations in the Building Standards Law in Japan. However, the fact buildings were constructed within the scope of the law does not mean that will not affect the surrounding residential environment and residents. While infringement of the right to sunlight has long been discussed, it is difficult to determine the impact. In particular, the impact on the psychological and physiological aspects and lifestyles associated with changes in the residential environment caused by infringement of the right to sunlight has not been fully clarified. In this study, we investigate the effects of infringement of the right to sunlight on the psychological and physiological aspects and lifestyles of residents in an apartment building where right to sunlight can be infringed, along with changes in the residential environment, over a period of about one year.

2. Methods

The experiment in this study was conducted on a seven-story apartment building. Construction of an eight-story apartment building was underway on the adjacent land to the south side of the subject apartment building, and this study was conducted in parallel from the early stage of its construction in spring (April-May), summer (July-August), and winter (December) of 2022, and the fourth experiment is scheduled to be conducted in spring (March) of 2023. The duration of each seasonal experiment was one week with approximately twenty residents as participants.

In the experiment, about twenty participants were asked to complete seven questionnaires and a Stroop test to measure psychological quantities and evaluate sleep. Moreover, they were asked to wear activity meters and record their heart rate to measure physiological quantities, such as sleep variability, and illuminance, temperature, and humidity were measured in the participants' apartments, and recorded at two-minute intervals throughout the experiment. Besides, noise of the construction was measured, and psychological quantities were measured through questionnaires with all sixty-nine households.

3. Results

We report the questionnaire regarding impression evaluation of residential environment, and the illuminance measurement results.

The impression evaluation of residential environment was conducted to all sixty-nine households (response rate: seventy-eight%), and the residents rated impressions of their residential environment using the semantic differential method on a scale of one-five based on pairs of opposing adjectives. The results of the questionnaire were analysed for each direction of apartments classified as south, east, and west, and for each floor level. Of the sixty-nine apartments in this apartment building, forty-five apartments face south, twelve apartments each face east and west. As the results of evaluation in each direction, the evaluation of south side showed a tendency to decline with each passing season. On the other hand, no significant changes were observed on the east and west sides throughout the three seasons. Although the changes in evaluation could be due to seasonal and weather effects, the fact that the evaluation of the east and west sides, which are not affected by the construction, did not change suggests that the change in evaluation of the south side is due to

the environmental changes caused by the construction. In addition, in the evaluation by floor level, there was a tendency for the evaluation of each floor to decline as the seasons progressed. The evaluation on the lower floors declined significantly in summer, while middle floors declined significantly in winter. The fact that the evaluation significantly decreased when the apartment building was constructed up to the height of each floor suggests that environmental changes may have influenced the decrease in evaluation. In addition, the evaluations on the upper floors declined at regular intervals as the seasons progressed. Since the construction was nearing completion in winter experiment, the lower evaluation in winter was influenced by environmental changes as well as other floors. In addition, the gradual decrease in the evaluation suggests that not only environmental changes caused by the infringement of sunlight, but also noise and dust from the construction work affected the evaluation.

As for the result of illuminance measurement, illuminance may be affected by lighting equipment, seasons, and weather, but a decrease in illuminance was observed in all rooms facing south with each passing season even the amount of all-day irradiation is usually at its maximum during the winter and the hours of sunlight are longer than during the summer in the south side. When compared to the progression of construction, the time of decline in illuminance coincided with the time when construction reached each floor. The same significant decrease in illuminance was observed in the rooms where residents spend less time, and each meter was installed in a location not affected by curtains. In addition, two apartments facing east, and west measured in the three seasons showed a decrease in illuminance in summer, spring, and winter, in that order. This is due to the influence of the amount of all-day solar radiation and hours of sunlight depending on the direction of the apartments. Therefore, the results of this experiment suggest that the influence of lighting equipment was relatively small and the change in illuminance was large due to changes in brightness caused by infringement of sunlight.

4. Conclusions

Although the impact of infringement of the right to sunlight have been unclear, the impression evaluation of the residential environment revealed that changes in the environment caused by the infringement of sunlight have a significant impact on the psychological aspects of residents. The results of the illuminance measurements also revealed that the illuminance decreased on the south side where apartment building is being built. The results obtained in this study suggest that environmental changes such as infringement of sunlight associated with the construction have impact on the psychological aspect of the residents. It is clear that the presence of buildings in close proximity not only has a physical impact on the residential environment, but also affects the psychological aspects of residents. As a future issue, it is necessary to analyse the effects of psychological and physical quantities affected by changes in the environment on physiological quantities such as circadian rhythm, and there is room for a combined study.

PO127

PROBLEMS OF MODERN LED LIGHT SOURCES PHOTOMETRIC MEASUREMENTS

Nikanenka, S.V., Jaskov, A.V., Kreidzich, A.V.
B.I. Stepanov Institute of Physics National Academy of Sciences of Belarus, Minsk, BELARUS
s.nikonenko@ifanbel.bas-net.by

Abstract

Generally during usually photometric measurements, it is necessary that the filament of source radiation takes a strictly predetermined position with respect to the photodetector and the optical axis of the photometric setup. Positioning errors of the filament relative to the optical axis of the measuring system significantly affect the accuracy of the measurement distance. This leads to an increase in the error in measuring the photometric characteristics of light sources. Accordingly, in order to reduce these errors, it is necessary to set the center of the filament of the radiation source as accurately as possible on the optical axis of the setup. Until recently, this task was greatly simplified by the fact that lamp manufacturers made a mark on the lamp bulb or indicated a reference plane against which measurements of its photometric characteristics were performed. This is especially true for standard incandescent or discharge lamps.

The intensive evolution of LED technology over the past 15 years and the development of new types of LEDs and LED lighting equipment necessitates a new look at the procedure for alignment radiation sources and determining the distance in photometric measurements of radiation sources. At the present time, when performing measurements of the optical characteristics of LED light sources, the recommendations of CIE 127:2007 are applied, on the basis of which international and national standards have been developed. According to these recommendations, the measurement distance is set between the plane of the detector aperture and the center of the LED package, when oriented to its mechanical axis. It is important to note that, as an example, CIE 127:2007 shows an individual LED in a hard plastic package with a single chip. This type of LEDs was traditional at the time. It was also noted that the mechanical axis of the LED and its axis of optical radiation can differ significantly.

Alignment and determination of the distance of photometric measurements at using a mechanical axis does not cause serious difficulties. However, to correctly measure the optical characteristics of an LEDs, it is undoubtedly necessary to measure the spatial distribution of its radiation.

However, in recent years, there have been a number of trends in the design of LED : firstly, it is the flat shape of the LED package. In this case, the radiating surface is often located deeper, relative to the outer dimensions of the case. Secondly, the number of LED chips in one package can be 4 or more. Thirdly, recently developed standard (reference) radiation sources or lamps include several LEDs or even dozens of LEDs, which, assembled in one radiation source, form a complex radiating surface. Moreover, the form of the secondary optics of modern LEDs can differ significantly from traditional LEDs, and the material, such as lenses, can be soft. When determining the measurement distance for these LEDs, the error can be up to 2% (for CIE Standard Condition B). And when accurately determining the base (central) point of multi-chip LED sources, the recommended mechanical (geometric) approach is inefficient, since the overall spatial distribution of radiation is significantly affected, for example, by the manufacturing technology of these LEDs. Accordingly, the traditional methods of alignment and determination distance at photometric measurements, those recommended in CIE 127:2007, are not very suitable for determining the photometric characteristics of modern LEDs and lighting equipment s based on them.

To solve these problems, the following can be proposed. First, to use the light center of the LED source or LED illuminator determinated on the parallax method as the measurement distance reference point. Secondly, to develop a new standardized image of an LED or LED

illuminator in the form of, for example, a rectangle, which will later be used in international standards.

The report also discusses the method and device for determining the light center based on the parallax method.

PO133

INVESTIGATING THE FRAME ASSEMBLY ISSUES OF NEAR-FIELD GONIOPHOTOMETERS USING A VIRTUAL INSTRUMENT AND THE MONTE CARLO METHOD

Pizág, B.[1], Nagy, B.V.[1]
[1] Budapest University of Technology and Economics, Budapest, HUNGARY
pizag@mogi.bme.hu

Abstract

1. Motivation, specific objective

The characterization of light sources as extended emitting objects is essential for their use in detailed simulations. Point source models might be sufficient for calculating lighting on a larger scale but are ill-suited for designing luminaires. Instead, the source's luminance is employed, represented by rays scattered over the emitting surface. However, constructing such datasets is rather complicated, often involving careful modeling of the source geometry and emission characteristics. Alternatively, the same data can be reconstructed from sets of luminance measurements. This process requires the use of a near-field goniophotometer system capable of capturing images at the correct positions and assembling them with high accuracy.

Even smaller errors in the assembly process due to faulty positioning can create artifacts and various discrepancies in the results. The article aims to present a system capable of estimating the impact of said errors in various system configurations. This is achieved through the use of a simulated environment and a virtual instrument. The paper focuses on analyzing the localized errors in the data created by inaccurate sensor positioning.

2. Methods

A virtual near-field goniophotometer system is constructed, capable of rapidly evaluating different measurements. Since the main objective centers around evaluating positioning-related issues, the optical model is simplified: It relies on the thin lens approximation and assumes an ideally sharp image at all times. Based on these assumptions, the ray trace calculations can be substantially simplified, leading to a fast and simple model.

Light sources are modeled using parametric functions over a spherical surface. This way, custom characteristics can be produced without introducing sampling issues related to discretized datasets. However, because of this, there can be substantial abstraction between the virtual and realistic datasets. While smoother characteristics might be representative of most emissive surfaces, the article investigates ones containing sharper value changes that are more visibly impacted by alignment problems.

The measurements are evaluated using the Monte Carlo method: The model's input variables are subjected to stochastic error (derived from pseudorandom number generation) based on a normal distribution with a predetermined standard deviation. The resulting camera positions are used to sample the luminance distribution, while the ideal positions are used when assembling the frames. As expected for Monte Carlo simulations, each measurement setup is repeated multiple times, forming a population of results that are subject to statistical analysis.

3. Results

The article presents a system capable of simulating measurement errors characteristic of various near-field goniophotometer configurations. Based on experiments conducted using this system, a model is presented between the magnitude of the errors and the various system and light source parameters. Due to the complex format of the luminance distribution data, various metrics are compared to evaluate singular measurement errors.

4. Conclusions

The presented virtual near-field goniophotometer system could serve as a tool for evaluating the capabilities of custom configurations in terms of the geometric accuracy of the produced luminance distributions, predicting possible limitations, and assisting further instrument design.

PO134

INNOVATIVE DEVICE TO VERIFY AND/OR CALIBRATE LUXMETERS (LIGHT METERS)

Quiroga, M. E.[1], Quiroga, M. A. [1]
[1] LUMINOTEST, Bogotá, COLOMBIA
ingenieria@luminotest.com.co

Abstract

1. Motivation, specific objective

The lux meter calibration methods have been present in the market for decades without any meaningful development. We understand there is no better pattern to calibrate lux meters than Standard Illuminant A, however, this pattern tends to be obsolete according to lighting trends and its difficult acquisition in the market. Currently, to calibrate a lux meter, a principle of measuring the variation of light intensity over a distance is used, which leads to arrange large rooms with long rail equipment, that allow the presence of this light intensity variations and use lamps type Standard Illuminant A with different intensities and with short useful lives due to its type of incandescent technology. The aforementioned innovative device detailed in this article, promotes a change in this paradigm and due to its recent development (close to obtain the patent), uses state-of-the-art technologies that makes a calibration or verification a faster, automated with a wider range process.

2. Methods

The measurement method used to calibrate and verify lux meters, works on the same principle of illuminance, changes of light intensity according to the inverse square law, but with a different approach which makes it novel, changing the principle linked to a distance, to one which takes the light intensity into account, wider and precise for the calculations. The source of light is a Standard Pattern with a singular lighting pattern, providing accurate readings for the light devices commonly used today.

3. Results

Thanks to a state-of-the-art technology used in this equipment, changes in lighting laboratories, companies and users of lux meters is paramount as it brings:

Saved spaces: A single desk or working station is enough to run the new equipment.

Processing times: Its automated management and the new design allows a wide measurement range, delivering reports with countless data in just a few minutes, much less than compared with manual and semiautomatic equipment readings.

Information management: Flexibility in configuring the number of measurements (more than 30), allows that the statistics analyzed from the reports delivered by the device, reveal a concordance of data output between measurements.

Eliminate misdiagnoses: Run measurements to assess spaces with equipment that does not align with metrological assurance requirements, is running the risk of guiding actions in the wrong way.

Meter robot: The technological innovation of its components manages to break the dependency that exists between the technical staff and the current equipment. It demands autonomy after its initial programming.

Photographic proof: From specialized software, objective evidence of measurements is obtained in real time, to support quality assessments or audits.

Patent: Submitted for approval by 2021 as an invention patent and also as a utility model.

Measurement traceability: Results can be linked to a reference PTB or NIST using the string documented in the initial standard calibration.

Wide measuring range: This apparatus can calibrate or verify measuring a point from 0 up to 120 klx.

Calibration interval management: The versatility and low cost of performing permanent verifications, objectively recognize the period calculation for future calibrations, reducing costs in redundant calibrations.

4. Conclusions

Now it’s easier to calibrate and/or verify lux meters. With LUXOTEST you have an automated solution.

This equipment is not intended to change lighting metrology, it only makes it easier by adopting current technological tools and well-founded measurement techniques, the way to manage calibrations and verifications of lux meters over time.

The fact of changing a large and spacious room to support a long-rail machine to calibrate lux meters for a small office or work space, points out the significant difference between conventional methods and current methods of lux meter calibration.

One of the biggest limitations when calibrating lux meters is the measurement range, this equipment allows you to measure a wide range from 0 up to 120 klx.

This device is autonomous in its function of calibration and/or verification of lux meters, which allows to do its work without human interaction during its operation and therefore, take advantage of their labour in other activities, which make an organization a better work space for the laboratory analyst or technician.

The robustness of the measurements is the product of a significant number of measurements. Repeatability and reproducibility can be effectively achieved with this apparatus, thus guaranteeing an appropriate validation exercise that results in a sustained method.

PO138

A DEVELOPMENT OF MICOR-PRISM ARRAYS ACHIEVING IMAGE PROJECTION BY PRINCIPLE OF LIGHTING OPTICS: OPTICAL DESING AND NUMERICAL ESTIMATION OF LIGHTING PERFORMANCE

Shichi, W.[1], Nakano, M.[1], Toyota, T[1]
[1] Industrial Research Institute of Shizuoka Prefecture, Shizuoka, JAPAN,
wataru2_shichi@pref.shizuoka.lg.jp

Abstract

1. Motivation, specific objective

A microprism array (MPA) is an optical element consisting of a two-dimensional array of tiny rectangular prism cells. By controlling the tilt angle and direction (rotation angle) of individual prism cells and then refracting light, the MPA can project a pattern of light and dark figures. This is a unique projector because the projected pattern is formed by multiple spotlights projected from the prism cells. Therefore, the projection principle of the projector with the MPA is different from that with an LCD or a digital mirror device (DMD) projector.

Recently, the projection of pictograms from a car onto the road surface to improve driving safety and to communicate between an autonomous vehicle and pedestrians has been proposed by some car companies and headlight manufacturers. Because the MPA makes it possible to create a compact pictogram projection system consisting only of the light source and the MPA, the pictogram projection system using the MPA can be easily integrated into the vehicle.

However, the development of the projection device using the MPA has not been established because it is difficult to precisely fabricate the MPA. In addition, there is little knowledge about the projection performance of the MPA.

The purpose of this study is to investigate the number of prism cells required for the desired pictogram and to evaluate the blur of the projected pictogram in order to enable the efficient design of the pictogram projection optical system using MPA.

2. Methods

A projection system was designed using the optical design software VirtualLab Fusion (LightTrans International GmbH) to project a 200mm square image onto a screen located 1m from the MPA, which consists of prism cells with a size of 0.08mm square.

Simulations were performed using the same software to estimate the illuminance uniformity and blurred width of the projected image as parameters of the number of prism cells and the distance between the light source and the MPA. The illuminance uniformity was defined as the minimum illuminance of the projected image excluding around its contour divided by the average one. The blurred width was defined as the width between the 10% and 90% positions of the average illuminance around the contour of the projected image. The effect of diffraction on the spotlight projected by a prism cell having a tilt angle was evaluated using Fraunhofer diffraction theory.

3. Results

The illuminance uniformity of the projected image improved with an increase in the number of prism cells, but tended to asymptotically approach a value of 0,8 which is not completely uniform.

The blurred width of the projected image tended to increase as the distance between the light source and the MPA became shorter when the light source had an area and a wide light distribution. In addition, prism cells with a tilt angle greater than 30 degrees were found to significant blur the projected image due to diffraction.

4. Conclusions

From our study results, we can estimate the number of prisms required to project a pictogram image with a set illumination uniformity.

In addition, our study results indicate that a projected pictogram image with less blur can be obtained by using light source with a small emission area or by reducing the distance between the light source and the MPA. The effect of diffraction on the blur of the projected pictogram image has to be considered when using prism cells with a large tilt angle.

This knowledge will help us to more efficiently design pictogram projection system using the MPA.

PO139

SNAPSHOT AND LINESCAN HYPERSPECTRAL IMAGING FOR VISUAL APPEARANCE MEASUREMENTS

Slembrouck, N.[1], Audenaert, J.[1], Leloup, F.B.[1]
[1] KU Leuven, Department of Electrical Engineering (ESAT), Ghent, BELGIUM
Nathan.slembrouck@kuleuven.be

Abstract

1. Motivation, specific objective

Hyperspectral imaging is a promising technique for evaluating the visual appearance of materials and coatings. It provides us with both spectral and spatial information at the same time, thus allowing for a more complete characterization of the appearance of materials. In comparison to a spectrometer for example, a hyperspectral camera also gathers spatial information. In comparison to RGB camera-based measurement systems, the spectral information from hyperspectral cameras is more comprehensive and accurate. With hyperspectral cameras, one can measure the colour differences on different locations of a sample, or measure multiple samples and even entire objects, rooms,… at once.

The objective of this study is to compare the performance of hyperspectral cameras to conventional instruments for measuring the reflectance of diffuse colour samples. Diffuse samples were chosen because these have less variation in their spectra when measured under different circumstances. This means that a high inter-instrument agreement is expected. Two types of hyperspectral cameras will be used: one linescan camera and one snapshot camera. These two cameras will be compared to two commercial devices: a desk mounted spectrophotometer and a portable multi-angle spectrophotometer.

In addition, the two hyperspectral cameras will also be compared against each other. Linescan cameras and snapshot cameras have different working principles, which causes them to have different advantages and disadvantages. These were examined on a theoretical basis, and are illustrated in practice.

2. Methods

First, the fundamentals of the two hyperspectral technologies are explained on a theoretical basis, with an emphasis on the differences between the two. From these principles, the theoretical benefits and limitations of each technology can be explained.

Second, in order to examine and demonstrate the two hyperspectral technologies in practice, one linescan and one snapshot camera have been characterized in the lab. The proper measurement procedures and setups were examined. The measurement of reflectance spectra requires the correct light source, measurement geometry and reference/calibration measurement. This process is explained in detail.

Third, colour measurement results obtained with the hyperspectral cameras are compared against results from the two spectrophotometers. This is done by measuring a ColorChecker chart. The spectrophotometers use different geometries and calibration standards. For this reason, all instruments have to be calibrated to read the same measurements. The calculations for this calibration were also determined. Different metrics are used to compare the quality of the measurements between the four devices. First-order statistics of these metrics are calculated in order to evaluate the variation between different measurements.

3. Results

Regarding the characterization of the cameras, the dark current for the snapshot camera is smaller than the dark current of the linescan camera. Both camera sensors behave linearly, which means they could also be calibrated for spectral radiance. The linescan camera has a higher spectral resolution than the snapshot camera, while the spatial resolution is approximately the same for both systems. As predicted from the theory, the linescan camera is slower than the snapshot camera. However, the images of the linescan camera are sharper, which means that the spectral distribution will be more accurately mapped to the correct spatial location and smaller details can be measured.

When comparing measurements obtained with the hyperspectral cameras against each other and against the spectrophotometers, a good agreement regarding the results between all devices has been achieved. The agreement between the two spectrophotometers is however slightly better than the agreement of these devices with the hyperspectral cameras. The hyperspectral cameras show more variation in their measurements for different colour samples.

4. Conclusions

Both hyperspectral cameras are suitable for appearance measurements. When measuring small details, scanning cameras might be better. For other applications however, snapshot cameras are faster and therefore more user friendly. The main culprit of the snapshot system is the sharpness of its pictures. This can however be enhanced by several different techniques, like machine learning based methods or pan sharpening.

Future research will focus on trying to enhance the sharpness of pictures taken by this snapshot camera and developing applications where hyperspectral cameras prove to be advantageous in comparison to other appearance measurement methods. Also, other samples than diffuse samples have to be included. It is expected that finding instrument agreements for non-diffuse samples will be more difficult, since non-diffuse samples show more variation in their spectral reflectance under different geometries.

PO144

A DEVELOPMENT OF MICRO-PRISM ARRAYS ACHIEVING IMAGE PROJECTION BY PRINCIPLE OF LIGHTING OPTICS: FEASIBILITY STUDY ON THE IMPLEMENTATION

Toyota, T.[1], Yanagihara, W.[1], Tashiro, T.[1], Shichi, W.[1], Nakano, M.[1]
[1] Industrial Research Institute of Shizuoka Prefecture, Shizuoka, JAPAN
toshihiro1_toyota@pref.shizuoka.lg.jp

Abstract

1. Motivation, specific objective

MPA, stands for micro-prism array, consists of arrayed micro-prisms which called cells. Each cell behaves like dividing original light source into arrayed pseudo-spot light sources. Optical axes of each pseudo-spot light sources are manipulated by angle and face normal of prism surface of each cell which forms MPA. Therefore, MPA can project pictograms at arbitrary distance in far-field by overlapping these spot lights from single light source. Sharpness of pictograms tends to decrease than imaging optics because MPA follows principle of lighting optics and it is difficult to improve.

MPA brings novel image projection technique with simple optics and small number of optical components to the industrial fields like in-vehicle lighting devices which require small packaging. However, it is difficult for conventional injection molding technology to machine dies of micro-prisms having sharp edges.

Therefore, this study aims to examine feasibility of molds fabrication by combination of stereolithography and electroforming in order to realize mass productions for such microscopic-shaped optical components.

2. Methods

Firstly, MPA model has been designed in order to project one pictogram by optimizing tilt angles and face normal of cells using optical CAE software (LightTrans International GmbH, VirtualLab Fusion). The projection model has been consisted only one MPA and one light source. Distance between MPA and light source has been 5mm. Projection of an arrow shape to the area of 300mm width by 150mm height at a distance of 1,000mm has been targeted. MPA model consists of 20 by 20 arrayed cells. Footprint of each cell has been 0.1mm by 0.1 mm and height of each varied depending on the tilt angles of those designed. A fibre-coupled LED (Thorlabs, Inc., MINTF4) has been supposed as light source (Diameter: 0.4mm, Beam angle: 23°, nominal wavelength: 554nm and total luminous flux: 5.4lm) so that point light has been suitable for light source of MPA.

Secondary, MPA has been fabricated as master for electroforming by femtosecond laser stereolithography instrument (Multiphoton Optics GmbH, LithoProf3D-GSII). Hatch distance of X-Y axis has been set to 500nm and slice distance is set to 200nm. MPA has been printed on the optical glass plate made of BK-7. Transparent hybrid polymer (Micro Resist Technology GmbH, OrmoComp) has been used for printing material.

Finally, using the master formed by stereolithography, nickel mold has been formed by electroforming optimized for micro-structures.

3. Results

Tilt angles of each cell, consisting MPA model designed, randomly varied between 0degree to 15degree and maximum height of cells are 0.048mm. In the optical design, a line drawing of shape has been given as ideal original images. However, blur of projection image has been expected by result of lighting simulation in the MPA model designed. Such blur caused by size of the original light source is expected.

Master has been fabricated by stereo lithography with about 1km printing trajectories. Printing speed with optimized parameters has been 100mm/sec and total printing time has been about 17 hours. Relative printing error of tilt angles of cells is reached around 1% and it is not depending on the designed angle of each cell. Surface roughness parameter (Sa) on each cell is distributed around 100nm. Master having an enough quality as optical component by the stereolithography could be fabricated. On the other hands, projection image by master shows same tendency of blur predicted by simulation. Average illuminance of projection image measured by illuminance meter (KONICA MINOLTA, INC., T-10) is approximately 33.3lx.

Nickel mold of MPA using the master has been successfully fabricated. Tilt angles and surface roughness of each cell are finely transferred from master to mold. Describing the quality briefly, difference of tilt angle of each cell between master and mold shows small deviation (σ=0.30). However, this error will be considered as same as human error of measurement operations. On the other hands, surface roughness of each cell is slightly increased. The reason will be expected due to the adhesion of particle lifted off from masters on the mold. In fact, large residuals, a part of master, is observed on the corner of the mold. However, these deposits will be removed by chemical cleaning or test shots of molding.

4. Conclusions

In this study it has been found that combinations of stereolithography and electroforming can be achieved forming molds of MPA consists of micro-prisms. This method will be applicable for many of micro-structured optical components.

In the future work, evaluation of the quality of MPAs produced by the mold are planned.

PO153

CALIBRATE THE ABSOLUTE LUMINANCE OF HDR PANORAMAS USING A REGULAR TETRAHEDRON ILLUMINANCE METER

Xia, L[1], Zhang, T. T.[1], Liu, X.F.[1]
[1] College of IoT Engineering, Hohai University, Changzhou, 213000, CHINA
xialing@hhu.edu.cn, xfliu@hhu.edu.cn

Abstract

1. Motivation, specific objective

The HDR panoramic images have been taken as a new camera-aided lighting measurement technology. While the shooting of HDR panoramas has become quite easy with all kinds of commercially available software, the conventional luminance calibration procedure is complicated using a spot luminance meter and standard grey cards. This paper aims to propose a solution to calibrate the luminance of the HDR panoramas based on the physical measurement of scalar illuminance using a regular tetrahedron illuminance meter.

2. Methods

The theoretical explanation of how scalar illuminance can be approximated based on the measurements of a regular tetrahedron was given. The performance of a regular tetrahedron illuminance meter were tested under 205 indoor and 2233 outdoor panoramas from the Laval HDR databases. Fifty measurements were conducted under each panoramic map by rotating the regular tetrahedron meter.

3. Results

The results show that the regular tetrahedron illuminance meter gives very reliable measurements on scalar illuminance with an average absolute error being 1.7% over all the measurements. Furthermore, the average relative standard deviation of the 50 measurements was found to be 2%. Previous research has shown how the scalar illuminance can be derived from the zeroth order of the spherical harmonics decomposition of a HDR panorama. Thus, taking them together, we get a new method to calibrate the HDR panoramas based on the measurements of scalar illuminance.

4. Conclusions

The use of a regular tetrahedron illuminance meter has the potential to be embedded in a panoramic camera for the continuous calibration of fast changing scenarios.

PO175

APPLICATION OF VISIBLE LIGHT COMMUNICATION TECHNOLOGY IN DIGITAL OPERATING ROOM

Wang, X.[1], Song, J.[1]
[1] Tsinghua University, Beijing, CHINA
wangxiaofei@tsinghua.edu.cn

Abstract

1. Motivation, specific objective

Visible light communication (VLC) is a wireless communication technology that uses visible light for illumination and communication at same time. Compared with the conventional wireless communication technology with radio channels, VLC transceiver units can be integrated with the existing lighting system. VLC system has advantages such as energy saving, easy deployment, no radio interference, electromagnetic compatibility and so on. It also has the disadvantages of being easily blocked, interrupted and interfered by sunlight. With the technology progress of medical digitization, traditional hospitals are transforming into digital hospitals. More and more medical devices with wireless communication capabilities are being deployed, and more wearable devices are used in patients' body, such as pacemaker. Serious electromagnetic interference problem should be considered to affect medical safety. In this project, VLC technology is used in the digital operating room to reduce electromagnetic interference as an application experiment.

2. Methods

The operating room always uses artificial lighting system and is a good place for VLC usage without interference of sunlight. With the increase of digital equipment, digital operating rooms are plagued by more and more radios interference. This situation will affect the safety of surgery and the patient's healthy with pacemaker and other important equipment inside the body. In the experiment, the project team with electronic engineering ability, deploys VLC system in a real digital operating room. Shadowless operating lamp is modified as VLC receiving unit (Signal receiving module), the core receiving and control module of VLC system. Shadowless operating lamp, as the lighting source in the operating room, can theoretically produce a full range of transceiver without dead angle and solve the problem of visible light interruption caused by shading. On the other hand, in the operating room, six potential device deployment points install the VLC transmission (Signal transmitting module) module. In one hour simulated operation, the interference of doctors and nurses with VLC system at different locations was simulated. Experiment data are collected comprehensively.

3. Results

The application of the VLC technology in the digital operating room achieved preliminary results. The experiment proved that it was feasible to carry out two-way data transmission through the multi-transmitting point method in the actual operation when shadowless operating lamp are used as the arbiter control. The communication would not be interrupted or interfered by the movements of doctors and nurses.

4. Conclusions

The experiment of VLC technology in the digital operating room proved that VLC can be well applied in the digital operating room, especially relying on shadowless operating lamp as the base station. VLC is a potential way to reduce electromagnetic interference, maintain the safety of patients' implantable electronic devices, and improve the security of communications in digital operating rooms and medical environments. Particularly, shadowless operating lamp is the natural VLC centre in the operating room.

CORRELATING PHOTOPIC AND MELANOPIC REFLECTANCE TO SURFACE COLOUR ATTRIBUTES FOR INDOOR ENVIRONMENTS DESIGN

Bellia,L[1]**.**, Diglio F. [1],Fragliasso[1], F., Sharma A[2].
[1] Department of Industrial Engineering, University of Naples Federico II, Naples, ITALY, [2] Department of Architecture, University of Naples Federico II, Naples, ITALY
bellia@unina.it

Abstract

1. Motivation, specific objective

Integrative lighting concept is by now fundamental in lighting design. To balance visual and non-visual effects of light, designers must carefully control the overall characteristics of the luminous environment, even accurately choosing surfaces' materials and colours.

Each opaque surface, reflecting light, is a secondary light source. Their optical characteristics impact on several design aspects. Indeed, surfaces reflectance contribute to determine illuminance levels and are responsible for luminance distribution in the environment, influencing glare perception and the overall pleasantness of the space. Interactions between light and materials are critical in affecting colours perception and play a role in determining the spectral content of the irradiance at the eye, in turn able to influence people's circadian response.

Despite all the mentioned aspects, choices about colours and materials are often based on aesthetical reasons exclusively. Sometimes this is due to the difficulty in understanding a priori how the use of a material would overall affect the luminous environment.

Previous studies treated this topic. Some of them deepened the relationship between indoor walls reflectance, illuminance values at the work-plane, and consequent implications in terms of energy consumptions. Some others focused on the effects of walls colours on people's circadian response.

Generally, these studies exclusively focus on one specific aspect at a time. Often, they analyse a limited range of materials or colours without giving general indications for design choices. Moreover, materials' characteristics are usually evaluated when applied in a specific space, neglecting their potential in affecting visual and non-visual effects, irrespective of the way they are used in the environment. In this respect, previous research proposed the so-called melanopic reflectance in addition to the visual one (even called photopic reflectance) to describe the potential of a material in reflecting radiation able to stimulate intrinsically photosensitive retinal ganglion cells (ipRGCs). The ratio of melanopic to photopic reflectance (M/P) is a useful parameter to understand material behaviour considering both visual and non-visual aspects. When this ratio is equal to 1, the percentage of reflected radiation able to stimulate visual system (light) and the percentage of reflected radiation able to stimulate ipRGCs are equal.

Classification of materials based on M/P ratio could be helpful to drive designers' choices. For example, regarding the colours, M/P values could be declared in the typical atlas used for chromatic palettes design.

Based on these premises, the goal of the paper is to evaluate melanopic, photopic reflectance and their ratio (under D65) for a big number of different samples selected by using the natural colour system (NCS), applying a systematic analysis method, to infer useful indications for design purposes.

2. Methods

About 180 colour samples were selected from the NCS. The selection included the four unique hues (red, yellow, green, and blue) and, for each quarter in the colour circle, samples with a combination of 30% and 70% of the two unique colours were chosen. In this way 12 hues were identified. Then, for each hue all the samples characterized by 5%, 30% and 60% blackness were selected.

Spectral reflectance of each sample was measured with a spectrophotometer (measurement range 360 nm - 740 nm with a 10 nm step). Then:

- photopic and melanopic reflectance under D65 were calculated,
- M/P ratios were obtained,
- relationships between M/P ratio and the chromatic attributes were inferred.

3. Results

The following main results were obtained.

Colours belonging to the Red-Yellow quarter are all characterized by M/P ratios lower than one, with the lowest values registered for the pure yellow, irrespective of the blackness. The M/P values increase (tending towards one) with red content increase. For colours belonging to the Red-Blue quarter, M/P values are lower than 1 when the blue content is lower than 30%, whereas for samples with 30% blue and 70% red (for all blackness values) M/P ratios are almost equal to one. Furtherly increasing the blue content, the M/P values increase. The highest values are registered for pure blue. As regards the other two quarters, the samples corresponding to pure green have M/P ratios very close to 1, whereas the adding of yellow and blue reduces and increases the M/P values respectively.

Once a specific hue is selected, maintaining steady the blackness, on chroma varying it is possible to observe a linear relationship between the photopic and melanopic reflectance values. The chroma reduction (and consequently the whiteness increase) determines, of course, an increase of both reflectance values. Moreover, reducing the chroma, the M/P ratios tend towards one (increasing for samples belonging to the red-yellow and green-yellow quarters and decreasing for the two others). Based on these results, it can be inferred that for each hue, selecting a specific blackness, it is possible to find a linear correlation between the chroma and the M/P values. Therefore, a correlation analysis was performed, the relative equations useful to calculate the M/P values based on the chroma ones were obtained. Confirming the goodness of the model, it was found that the corresponding R^2 values were higher than 0.9 in 84.6% of the observed cases.

Finally, from the complete obtained database, samples were grouped in different categories depending on M/P values ranges for practical design purposes.

4. Conclusions

Surface finishings should be selected evaluating their capacity in providing a comfortable space, considering the overall people's wellness accounting for both visual and non-visual effects of light. The work demonstrated that the analysis of M/P ratios can be a helpful tool for lighting designers. Relations between chromatic attributes and M/P values were studied. Indications useful for designers were given, and a model to obtain M/P ratio for each colour as a function of chroma (being blackness steady) was proposed. In future works the analysis methodology could be extended to a higher number of chromatic samples and to other chromatic systems to verify if results are generalizable. Moreover, being reflectance values and M/P ratios depending on illuminants, future research should account for this aspect.

PO06

A SIMULATION-BASED METHOD TO QUANTIFY DAYLIGHT EXPOSURE AND ITS EFFECT ON THE ONSET OF MYOPIA IN PRIMARY SCHOOL CHILDREN

De Groot, S.J.[1], Brembilla, E.[1], Dahlmann-Noor, A.[2], Price, L.[3], Khazova, M.[3], Eijkelenboom, A.[1], Turrin, M.[1]
[1] Delft University of Technology, Delft, The NETHERLANDS, [2] Moorfields Eye Hospital, London, UK, [3] UK Health Security Agency, London, UK
e.brembilla@tudelft.nl

Abstract

1. Motivation, specific objective

The prevalence of childhood myopia is increasing, and light exposure, including lighting conditions at schools, is likely to be a contributing factor. In certain areas of the world, like in South-East Asia, data on childhood myopia has been collected for decades, building strong evidence of the severity and extension of the issue. On the other hand, data on European population is less easily available and does not provide a clear picture about the extent of the problem. Questions remain on whether the onset of myopia is less pronounced or is progressing at a slower pace in Europe compared to Asia. Furthermore, the principal environmental risk factors have been identified as being light exposure and focal distance but their relative weight on the onset and progression of myopia is still unknown.

Time outdoors during the day is a known risk factor for myopia outcomes, that is likely to be due to the difference in total light exposure. Light exposure is also related to other public health targets, including psychological wellbeing, and circadian and sleep health. Luminous exposure is one measure of personal exposure to light, based on illuminance measured at the eyes. However, continuous measurements at the eyes may be difficult to achieve in school children. Conversely, built environment modelling may consider exposures achieved at static points, but without estimation of the impact of movement inside and outside of the building. This suggests that bridging this gap is important for assessing light exposures in myopia studies in school children.

2. Methods

This study applies for the first time the techniques behind Climate-Based Daylight Modelling (CBDM) to evaluate daylight exposure in myopia studies. CBDM is a daylight simulation method that uses weather data to recreate realistic sky conditions within a 3D modelled scene and then calculates lighting measuring quantities by means of physically accurate simulation engines. It has been primarily developed for daylight sufficiency analyses, aimed at assessing the indoor performance of a building as the frequency of time for which electric lighting systems can be switched off and the related savings in terms of energy consumption. The model requires data about the sky conditions, typically in the form of solar irradiance (in W/m^2), about the geometry of the building and about the optical properties of the major surfaces (reflectance and transmittance). The results of the simulation are typically expressed as illuminance values (in lx) at specific points or grids inside the building; their temporal resolution is dependent on the available resolution for the outdoor weather data – which can vary from 1 minute to 1 hour – but can then be aggregated differently, as required by the scope of the analysis.

The present analysis focuses on two case study school buildings located in The Netherlands. One building is a new construction, completed in 2022, and the second building is a renovation, also completed in 2022, of an older construction from the 1920s. Both schools are aimed at children between 4 and 12 years of age, hence including the childhood stages during which the risk of developing myopia seems to be the highest. Classrooms for 6 years old children were selected for further measuring and monitoring campaigns.

It is important to notice that anyone of the model's inputs is accompanied by uncertainties that might lead to larger errors in the final results. The interaction of building occupants (pupils and teachers in this case) with the building is often hard to predict and can bring further uncertainties to the model. It was therefore decided to collect measurements of short-term luminous conditions and of optical properties in the actual buildings in order to validate the model and quantify the overall error. Illuminance measurement, including spectrally resolved ones, were collected at the students' sitting positions during the visits to the schools, while pupils were not present. Additionally, illuminance sensors were left in the classrooms for a few days during classroom activities, to record unexpected changes in light levels, due for example to the operation of shading systems and electric lighting.

Narrative evidence from teachers also allowed a better understanding of the schools' daily schedule, and of the expected movements of the classes between different parts of the school, for example time spent outdoors during breaks.

3. Results

The study is still ongoing but it is expected that the model will provide a reliable relative quantification of the weather-dependent daily variations in indoor light exposure. Even though absolute errors cannot be completely eliminated from the model, the achieved accuracy should be sufficient to draw conclusions on the typical light exposure experienced by school pupils. Furthermore, a cumulative metric such as daily exposure tends to reduce random errors found in transient simulation results.

4. Conclusions

This study tested the feasibility of using CBDM simulation techniques to conduct research on myopia in school children. Given the difficulties found in monitoring light exposure at the eye of children, built environment simulation offers the opportunity to collect a larger amount of data with more ease, even though the overall uncertainty is larger than with direct measurements. Simulated values of daily light exposure were found to be sufficiently informative about the expected exposure range for a number of classrooms environments. Future research should aim at including and validating additional variables that include the effects of head movements and movements between different spaces.

PO11

CALCULATING SPATIAL EFFICIENCY TO QUANTIFY INDOOR LIGHTING SUSTAINABILITY

Durmus, D.[1], Mahmoudzadeh, P.[1], Hu, W.[2], Davis, W.[2]
[1] Pennsylvania State University, University Park, USA, [2] University of Sydney, University of Sydney, AUSTRALIA
alp@psu.edu

Abstract

1. Motivation, specific objective

Humans spend a majority of their lives in indoor spaces, and architectural lighting plays a crucial role in occupant comfort, performance, and wellbeing. On the other side, lighting contributes to energy use in buildings and therefore to global climate change. Despite the energy savings introduced by the advances in solid-state lighting (SSL) technologies in the past two decades, there is a need to focus on complete lighting system performance. Currently, the energy efficiency of lighting is measured using luminous efficacy (unit: lm/W), the quotient of the emitted luminous flux and the power consumed by a light source. By definition, luminous efficacy can only quantify the effectiveness of an individual light source by considering the luminous flux output measured in a photometric lab. Depending on the spatial distribution and temporal use of the luminaire, the actual effectiveness of a light source can widely vary from installation to installation. In addition, smart lighting system savings cannot be characterised using individual light source efficacy. In short, current methods for quantifying efficiency do not holistically consider the actual effectiveness of lighting systems in the built environment. Instead of focusing on individual light sources, lighting application efficacy (LAE) should be utilised to holistically measure the sustainability of conventional and smart lighting systems.

2. Methods

A novel LAE framework has been recently developed to quantify the effectiveness of lighting in indoor environments. The LAE framework is based on the primary pathway of light: generation of light, light traveling through the space, and light contributing to visual perception. Consequently, the proposed LAE framework consists of three elements: luminaire efficiency, spatial efficiency, and visual sensitivity. Luminaire efficiency (commonly known as radiant efficiency) is the quotient of the radiant flux of the emitted radiation and the power consumed by the source. Visual sensitivity is the sensitivity of the visual system to visible optical radiation, which is commonly modelled using spectral luminous efficiency functions, such as the CIE standard observer. Spatial efficiency is the quotient of the radiant flux at a target (either observer field of view -FOV- or a work plane) and the total radiant flux emitted in a given space.

Spatial efficiency can be calculated using Radiance simulation software at any user-defined target(s): a) work plane(s) or b) occupant(s) field of view. To analyse the impact of different room characteristics, a set of simulations were performed in rooms of different sizes (3.5 m × 3.5 m × 3 m, 5 m × 5 m × 3 m, 9.5 m × 9.5 m× 3 m, 20 m × 20 m × 3 m), reflectance levels (floor: 0.1 / wall: 0.3 / ceiling: 0.4; 0.2 / 0.5 / 0.64; 0.3 / 0.6 / 0.8), luminaires with various luminous distributions (direct, direct/indirect, indirect), and area per luminaires (low and high density). Two sets of targets were generated: 1 m x 1 m horizontal work planes 0.76 m from the floor, and observers with a visual FOV of 30-, 90-, and 160-degrees with the view directions of North, South, West, and East.

The total radiant flux emitted to each room was calculated by summing the radiant flux from each light source. The radiant flux emitted from a light source was calculated by multiplying its radiant efficiency and power consumed from the luminaire. Since radiant efficiency is often not provided by the manufacturers, it was calculated by dividing luminous efficacy with the luminous efficacy of radiation. Luminous efficacy of radiation was calculated by multiplying

the normalised spectral power distribution of the light source with the CIE photopic luminous efficiency function.

It is reasonable to assume that light directly reaching the eye of an observer from the light source will have negative effects (glare). Therefore, spatial efficiency values were re-evaluated by subtracting the direct light coming from the light source (total radiant flux with surfaces set to 0% reflectance) from the total amount of radiant flux reaching the visual field of the observer when surfaces are at normal reflectance levels.

3. Results

Spatial efficiency values from the simulations for work plane and FOV were analysed separately. For work plane method, spatial efficiency varied between 0.001 and 0.42 with a median of 0.01 and standard deviation of 0.04. Room area, area per luminaire, surface reflectance, and luminous distribution were statistically significant predictors for spatial efficiency ($p < 0.0001$). For FOV method, spatial efficiency varied between 0.001 and 0.51 with a median of 0.01 and standard deviation of 0.05. Similarly, room area, area per luminaire, surface reflectance, luminous distribution, and visual field angle were statistically significant predictors for spatial efficiency ($p < 0.0001$). Unsurprisingly, there was a difference between visual field angles, where larger FOV increased spatial efficiency of the lighting. A multiple linear regression model was developed to estimate spatial efficiency based on input parameters ($R^2 = 0.9$). Results also suggest that taking glare into account can reduce spatial efficiency.

4. Conclusions

Current lighting efficiency metrics are limited to individual light sources and cannot quantify the efficiency of smart lighting systems' performance. Instead of individual luminaire efficiency (luminous efficacy), lighting application efficacy should be used to holistically quantify the effectiveness of architectural lighting systems. A recently developed LAE framework addresses this need by consolidating radiant efficiency, visual system sensitivity, and most importantly, spatial efficiency of lighting systems. Spatial efficiency, the amount of radiant flux reaching the target divided by the total emitted radiant flux into a room, can be calculated using Radiance simulation software either for user-defined work planes or occupants' visual field. Simulations show that spatial efficiency values are significantly affected by room size, luminaire density, surface reflectance, luminous distribution type, and visual field angle. Simulations also allow building predictive models for ease of use. The proposed LAE framework is organic and flexible in nature, allowing other researchers to add and modify each component to address more complex needs in the future.

PO12

ANALYSIS ON DAYLIGHT GLARE OF TYPICAL MODEL OF UNIVERSITY GYMNASIUM UNDER SPORTS BEHAVIOR

Fan, Q.[1], Zhang, M.[1], Liu, Y.[1]
[1] Tianjin University, Tianjin, CHINA
294634856@qq.com

Abstract

1. Motivation, specific objective

In the design stage of existing university gymnasium in China, usually on the premise of satisfying functions, more light will be introduced into the room or a large number of preference lighting facilities will be used, but less consideration is given to the influence of natural lighting and glare, resulting in poor experience caused by using only natural light in actual use, of which glare problem is the most serious. The research on natural daylighting uncomfortable glare is complicated due to the uncertainties of users'movement position and visual angle in University gymnasium.

2. Methods

Through research and development, it is found that badminton and basketball are used most frequently in University gymnasiums. Based on the high frequency activity points and visual angle of these two sports behaviors, 167 typical glare points (including 15 uniform spots, 120 badminton courts, 32 basketball courts) and 2 vertical viewing directions are obtained through the research method of observation-reduction-statistics. The uncomfortable glare in the gymnasium model is simulated and analyzed with the Rhino software Grasshhoper platform.

3. Results

The hourly DGP operating conditions of 20040 hours are simulated, the color order diagram of the DGP index of each point is drawn and compared statistically, the overshoot rate of the corresponding DGP index is calculated, the discomfort glare variation rule between the points is studied, and the main glare source and the reasons for the change are obtained by analyzing the hourly HDR brightness pseudo-color image of special points. Then according to the "most unfavorable principle" of lighting simulation, 15 points of uniform distribution method, 20 points of badminton court and 10 points of high frequency activities of basketball court are selected from 167 points based on sports behavior, which are representative points of uncomfortable glare simulation in typical gymnasium.

4. Conclusions

It is found that among the building types of large indoor space such as gymnasium, the influence of angle change on glare is higher than that of position change, and the periods of high glare occurrence, glare occurrence and reasons in different site types are summarized in order to avoid and improve the uncomfortable glare condition in interior during the early design of gymnasium.

PO16

LIGHTING EDUCATION: A COMPARISION OF BRAZILIAN AND ITALIAN CONTEXT

Daltrozo, J. G.[1], Martau, B. T.[1], Pellegrino, A.[2], Lo Verso, V.R.M.[2]
[1] Department of Architecture, PROPAR, Federal University of Rio Grande do Sul, BRAZIL, [2] Department of Energy 'Galileo Ferraris', TEBE Research Group, Politecnico di Torino, ITALY
jegodoy.arq@gmail.com

Abstract

1. Motivation, specific objective

Lighting and its effects have been a relevant topic of discussion in various fields such as architecture, engineering and medicine, for example. Several studies have shown that light defines spaces, and the dynamic light can alter perception, influence the circadian rhythm, mood and affect the quality of life on built environment. Also, lighting design can enhance or compromise architectural intent, increase the legibility of cities or make environments unsafe, reveal or distort the modelling of nature and objects.

Therefore, understanding lighting as a foundation of design process, on the most diverse scales, is essential for the training of a qualified professional. In contrast, in the educational field for architecture professionals, few publications presenting and discussing their teaching methods, learning assessments or descriptions of teaching programs are found. Therefore, there is a lack of research in this area, especially applied to the basic disciplines of undergraduate courses in Architecture, such as design practice and lighting.

This study is part of a wider research focused on lighting education. This research follows the hypothesis that it is possible to teach lighting in architecture design courses in a way that the student develops the competence to design considering the behaviour of light in internal and external spaces, as well as its impact in human health and wellbeing. As part of this great project, parallel studies are being carried out, such as surveying the gaps in teaching lighting based on questionnaires with graduates, based on interviews with teachers, documentary research and field research. For this study, results of questionnaires carried out with graduates in different countries such as Brazil and Italy will be presented.

2. Methods

The research has a quantitative approach. The sample included Brazilian's and Italian´s former architecture´s students selected by convenience. For the application of the present study, two stages were defined. In the first stage, two anonymous questionnaires were applied through the google forms platform and both were released on digital platforms aimed at Brazilian Architects. The objective of the first questionnaire was to identify lighting content present in graduation course curricula and the gaps of learning identified by the participants. The questionnaire was structured with 16 questions, 10 of which were multiple choice and 6 essays. The essays focused on topics such as teaching methodologies, number of hours of the lighting course and topics studied. The second questionnaire was applied with a focus on the needs faced in the professional life as an architect. There were 26 direct questions using the method of scales from one to five, where one was considered as "not very important" and five as "very important" or "not interesting" and "very interesting", depending on the question. In the second stage, the same procedures were applied to Italian graduates in order to compare the two realities concerning to lighting education. The questionnaires were applied from 2020 to 2023 and the data collected was organized and analysed using statistical methods. The results were discussed and presented through tables and graphics.

3. Results

The Brazilian sample consisted in 43 in the first questionnaire and 135 in the second one. The Italian sample consisted in the same number of participants. All participants, in both samples, demonstrated great interest in the lighting topic and understand it as a very important aspect of the design process from buildings to cities scale. The study identified

some differences from Brazilian and Italian organization of lighting courses in the architecture learning process. In Brazil, many courses of lighting design are disconnected from the design courses, what makes the learning process fragmented. In other way, in Italy, most of the lighting topics are discussed in the design courses, what results in a more integrated approach. The importance of lighting design is well understood in working practice even in Italian and Brazilian context. Although, Brazilian´s architects identified more gaps in their academic formation concerning light topics than Italian ones. This may be a directly result of the lighting teaching methods, that is much more integrated in Italy.

4. Conclusions

Lighting education still a very necessary theme of discussion in the architectural lighting field. There are different levels of quality in teaching practice, depending of the social, economic and cultural status of a country. This do not mean that we must have only one strategy for all the courses, but that is urgent to establish more integrated practices and a list of minimum obligatory topics that should be discussed in architectural courses around the world. The generalist or specialist approach in the architect education may influence in the considered importance of lighting education in each academic institution. This study can contribute to this discussion and may be amplified to more countries, to allow us the understanding of the actual lighting education panorama, to define strategies for development of the next generation of architects and lighting designers.

PO17

EMULATING DAYLIGHT IN A NEONATAL INTENSIVE CARE UNIT WITH A NOVEL SPECTRALLY TUNABLE LIGHTING SYSTEM

Cao, Y.[1], Zhang, K.X.[1,2], Brennan, M.[3], Soler, R.[4], **Greenberg, J.M.[5,6]**, Lang, R A. [1,6,7]
[1] Division of Pediatric Ophthalmology, Abrahamson Pediatric Eye Institute, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA, [2] Medical Scientist Training Program, University of Cincinnati College of Medicine, Cincinnati, OH, USA, [3] ZGF Architects L.L.P., Seattle, WA, USA [4] BIOS Lighting, Carlsbad, CA, USA, [5] Perinatal Institute, Division of Neonatology, Cincinnati Children's Hospital Medical Center, Cincinnati, OH, USA, [6] Department of Pediatrics, University of Cincinnati College of Medicine, Cincinnati, OH, USA, [7] Department of Ophthalmology, University of Cincinnati College of Medicine, Cincinnati, OH, USA

james.greenberg@cchmc.org

Abstract

1. Motivation, specific objective

Lighting impacts mammalian physiology through wavelength and time-of-day dependent pathways that are mediated by nonvisual opsins. Some of these pathways affect processes that are crucial to the outcomes of the neonatal intensive care unit (NICU) patient population, such as growth, metabolism, and retinal vascular development, providing the motivation for this project. Previous NICU designs focused on the provider perspective, with by brightly illuminating units 24 hours/day to promote close observation and monitoring. Subsequent decades saw an emphasis on recreating the intrauterine environment, with many NICUs becoming darker and quieter. However, this approach neglected the importance of circadian neurophysiology during fetal development, leaving preterm neonates with little to no circadian input. Biologically aware, cycled lighting environments that recapitulate the spectral composition of daylight as it progresses from dawn through dusk and interact with human light-sensing proteins offer a compelling rationale for addressing the challenges neonates experience. We introduce the development and use of a novel spectrally tunable lighting system (Spectral Lighting) to emulate daylight within the NICU of a tertiary pediatric hospital. Here, we explain our NICU lighting plan and demonstrate that it mimics the composition of daylight.

2. Methods

Six months of sunlight irradiance data were collected onsite to inform the development of a custom NICU lighting plan. Local sunlight data was collected using a calibrated spectrometer with a cosine corrector mounted on an elevated mast. A custom software package facilitated continuous data collection with a pre-specified measurement interval and integration time. Irradiance data was calibrated using a formula that considered dark measurements, calibration spectrum, collection area, integration time, and wavelength spread. The Spectral Lighting System employed 6 distinct LED channels, and the user interface was used to create a composite output of six channels. We analyzed the wavelength composition of this data throughout the day by assessing photon flux across three wavelength ranges: (1) 380 – 430 nm (violet), which corresponds to the absorption curve of opsin 5, (2) 430 – 530 nm (blue), which corresponds to the absorption curve of opsin 3 and opsin 4, and (3) 630 – 730 nm (red), which aided in balancing the overall spectral composition. Key frames were assigned to desired times to create a Spectral Day, and each key frame's spectral power distribution can be exported through the user interface. Colorimetric data and additional color rendition characteristics were also generated.

3. Results

A novel spectrally tunable hospital lighting system that varies intensity, timing and spectral composition was developed through an interdisciplinary collaboration between lighting experts, clinicians, and basic science researchers. Local spectral data was collected to optimize the agreement between the lighting system and the local environment, and where the violet and blue wavelength ranges were of particular focus. This spectral lighting system has substantial improvements in mimicking the spectral qualities of natural daylight compared to former NICU facility lights, and further studies are needed to examine the biological thresholds for opsin responses in neonates.

4. Conclusions

By recapitulating the spectral composition of daylight and interacting with human light-sensing proteins, this system represents a radical advance over previous circadian based lighting designs. We sought to develop a customizable lighting schedule that best mimics the solar day based off local spectrometric measurements. The resulting lighting plan is a current standard of care in our brand-new Level IV NICU. Further studies are in development to determine the full potential of the system and to optimize its use in unique patient and study populations. Overall, this paper demonstrates the potential for interdisciplinary collaboration to address complex challenges in healthcare lighting design, opportunities to improve patient outcomes and underscores the need for continued research and development in this area. Finally, this novel system enables the execution of clinical research to investigate the biological impact of opsin-mediated light sensing in human health and disease, which have not been previously possible in clinical settings.

PO18

WINDOW-VIEW-RECOGNITION BASED ACCEPTABLE DYNAMIC DAYLIGHTING OF RESIDENCE

Hong, L.S.[1], Lin, Y.M.[1], Ma, R.Y. [1], Zhang, X.[1]
[1] Tsinghua University, Beijing, CHINA
hls19@mails.tsinghua.edu.cn

Abstract

1. Motivation, specific objective

Daylight has been regarded as one of the principal environment factors in residential buildings. Especially in the in- and post-pandemic era, people are likely to spend more time at home. It would attract increasing concerns about the impact of daylight on energy efficiency, occupants' health and well-being in residences. However, for the complex individual preferences and multiple climates, there is little consensus on daylighting requirements for residence. Therefore, this paper intends to figure out acceptable thresholds for the dynamic daylighting in residence by integrating the daylight values with the subjective evaluations of the residents. As for the difficulty of field measurement and respective simulation for daylight, window-view-recognition based daylight prediction might be a suitable method to collect data and calculate daylight values of subjects' residences.

2. Methods

First, pre-trained Convolutional Neural Network (CNN) model will be used to obtain the obstruction information of the window view images, and then the Random Forest machine learning algorithm will be trained to predict annual daylight illuminance, based on the obstruction information of window views, weather data, and other relative parameters. The test will be set in Beijing to verify the flow path of this topic: 1) A questionnaire survey will be conducted in Beijing to obtain residents' basic information, window views and daylighting evaluation in their living rooms. With the collected residence data and the images of window views, daylight values of each subject's residence can be calculated by the machine learning model. 2) Correlation analysis between the daylight values and subjective evaluations will be performed to find the acceptable thresholds for residential daylighting.

3. Results

The preliminary machine learning model has achieved a mean absolute error (MAE) less than 8% when predicting annual daylight illuminance values. With further fine-tuning, this model may improve the accuracy and robustness to decrease the disturbance during questionnaire survey. This section will show the satisfaction, brightness, and other subjective evaluations of residential daylighting conditions in Beijing under the current residential design. It will be presented whether there is a significant correlation between the daylight values and residents' evaluations. If so, the thresholds for acceptable dynamic daylighting in Beijing can be calculated. If not, other possible influence factors will be analysed, such as the differences between seasons and personal characteristics.

4. Conclusions

This paper could figure out the feasibility of the window-view-recognition based method for daylight prediction. It also investigates the conditions and residents' satisfactions for residential daylighting in Beijing under current planning/design regulations. The flow path of window-view-recognition based acceptable dynamic daylighting of residence can be testified. For further research, this flow path will be tested in more cities located in different climate zones. This series of exploration can be considered as a reference for the setting of daylighting standards.

PO20

PROPOSAL FOR A METHOD OF EVALUATING CONTRAST GLARE AND SATURATION GLARE IN DAYLIT INTERIORS USING VERTICAL ILLUMINANCE AT THE EYE

Ito D. [1], Ohki, C.[2]
[1] Nippon Institute of Technology, Saitama, JAPAN, [2] Obayashi Corporation, Tokyo, JAPAN
ito.daisuke@nit.ac.jp

Abstract

1. Motivation, specific objective

It is stated that the cause of the sensation of discomfort glare appears to be a compound of two effects, a contrast effect and a saturation effect, which can cause glare in daylit interiors. The Daylight Glare Probability (DGP) formula was to consider the saturation effect and the contrast effect by using the vertical illuminance at the eye and the CIE Glare Index (UGR) in one equation. On the other hand, Predicted Glare Sensation Vote (PGSV) provides two equations, for the contrast effect and for the saturation effect. Generally, these glare metrics are calculated for the luminance distribution image and software such as Evalglare, however a simpler method is required. The purpose of this study is to develop a practical method in which vertical illuminance at the eye is mainly used to predict both contrast glare and saturation glare.

2. Methods

PGSV for the contrast glare, showing 1.2 of threshold value between acceptable and unacceptable, evaluate glare by using the luminance of source, background luminance, and solid angle of the light source. Assuming that the background luminance is indicated as a function of the luminous flux from the window and the interior average reflectance, the threshold of the window luminance resulting 1.2 of PGSV can be calculated. The threshold vertical illuminance at the eye can be obtained from the luminance of the window, the configuration factor of the window and the average reflectance of the interior surface. Since PGSV for the saturation glare can be calculated from the average luminance, the threshold value of the vertical illuminance at the eye resulting 1.2 of PGSV can be obtained by converting the average luminance into the vertical illuminance at the eye.

Measurements were conducted in nine offices in the Japanese metropolitan area to examine the accuracy of the proposed equation. The solid angle of the window, luminance of the window, vertical illuminance at ethe eye, and interior reflectance were measured. A total of 18 conditions were measured: with or without electric lighting, with three blind conditions (no venetian blinds, 0° of slat angle, and 45° of slat angle), and three measurement points (1 m, 3 m, and 5 m from the facade). A CCD camera with a fisheye lens was used to measure luminance of the window and the solid angle of the window. The height of the measurement point was 1200mm for luminance of the window, solid angle of the window, and vertical illuminance at the eye. The surface reflectance of the ceiling, floor, and wall were measured at five points each using a colorimeter.

3. Results

For calculation, the luminous flux from artificial lighting was excluded. Without blinds, the vertical illuminance at the eye measured were higher than that calculated. On the other hand, the calculations were generally accurate for the conditions with the blinds. Approximate values for window area and interior surface reflectance for metropolitan area offices were obtained.

To examine the validity of the proposed equation, threshold values for vertical illuminance at the eye were calculated for two buildings with different measured window areas. The

calculated results were also compared with DGP. The vertical illuminance at the eye threshold for saturation glare which is not affected by the solid angle of the window is about 3600 lx. In a building with large window area, the difference between contrast glare and saturation glare is small. In a building with small window area, the threshold value of vertical illuminance at the eye at 5 m from the window is about 1900 lx, and contrast glare t must be evaluated in the building with small window area. . Thus, the proposed equation can be adapted to various types of the building, and the contrast glare and saturation glare can be evaluated by the vertical illuminance at the eye.

4. Conclusions

A method for evaluating contrast glare and saturation glare using vertical illuminance at the eye was proposed, and measurements were conducted in nine offices in the Japanese metropolitan area to confirm its accuracy. In the case of offices with blinds, the calculated and measured values of vertical surface illuminance by the proposed equation were generally in agreement. The vertical illuminance at the eye thresholds for discomfort glare were calculated for actual offices using the proposed equation. In the case of offices with large window area, the difference between the vertical illuminance at the eye thresholds for contrast glare and saturation glare was smaller because the background luminance was higher. On the other hand, in the case of an office with small window area, the difference between contrast glare and saturation glare was larger because the background luminance was smaller. By using the proposed equation, it is now possible to evaluate the contrast glare and saturation glare in daylit interiors according to the vertical illuminance at the eye. Therefore, discomfort glare in daylit interiors can be evaluated simply.

PO23

THE EFFECT OF INDOOR LIGHTING ON HUMAN PSYCHOLOGY AND PHYSICAL ACTIVITY DURING COVID-19 LOCKDOWN: A SURVEY

Zhao, C.[1], **Lin, Y.**[1,2,3,4]

[1]Institute for Electric Light Sources, School of Information Science and Technology, Fudan University, Shanghai 200438, CHINA, [2]Institute for Six-sector Economy, Fudan University, Shanghai 200433, CHINA, [3]Human Phenome Institute, Fudan University, Shanghai 201203, CHINA, [4]Intelligent Vision and Human Factor Engineering Center, Shanghai 201306, CHINA

ydlin@fudan.edu.cn

Abstract

1. Motivation, specific objective

Emergency lighting is only used in specific situations, but it is a very important component of a lighting system. Natural disasters (like earthquakes, tsunamis, strong winds, rainstorms, snowstorms, plagues, geological landslides, solar storms, etc.) and unnatural disasters (like wars, fires, mine collapses, railroad derailments, grid failures, etc.) usually caused large-scale power outage situation. According to the theory of Maslow's hierarchy of needs, the most basic needs of the disaster victims are physiological needs and security needs. However, in this emergency situation, the lack of light source brings great distress to the basic physiological needs of the affected people, and at the same time, the serious disaster also brings great psychological trauma to them. Emergency lighting system to meet the basic needs of life, moreover, the light source with the appropriate illumination and correlated color temperature can also bring a sense of security and psychological comfort. The coronavirus disease-2019 (COVID-19) related lockdowns provided a good opportunity to obtain comprehensive datasets. From March to May 2022, a plague of COVID-19 broken out in Shanghai, China, then strict prevention measures were implemented. During this period, we conducted a survey of people in home isolation, including home lighting environment, light exposure behaviour, mood, sleep quality, physical activity and isolation effects, to assess the impact of emergency lighting on human psychology and sleep, and to provide a reference for emergency lighting settings.

2. Methods

Due to the strict isolation prevention measures, we used an online survey in this study, which included basic personal information, living conditions during isolation, light environment in home, light exposure behaviour assessment (LEBA), Pittsburgh sleep quality inventory (PSQI), international physical activity questionnaire (IPAQ), profile of mood states(POMS), stimulating substances, and isolation impact of COVID-19 survey. Finally, 311 questionnaires were collected.

3. Results

The results showed that participants who used bright-cool light during isolation showed lower depression ($p<0.001$) and higher vigour ($p=0.041$), yet also has the latest sleep onset time. An improvement of subjective sleep quality ($p=0.036$) was significantly correlated with decrease of phone and smartwatch in bed.

4. Conclusions

Based on the results of this study, during the COVID-related lockdown, depression and vigour were positively affected by bright-cool light. However, long-term use of bright white light also delays the sleep onset time. Which provided a reference for designing light in emergency.

PO61

HOW DAYLIGHT LED INFLUENCE HUMAN VISUAL AND NON-VISUAL PERFORMANCE

Li, N.[1, 2], Dai, C.[1], **Lin, Y.**[1, 2, *]
[1] Department of Light Source & Illuminating Engineering, School of Information Science and Engineering, Fudan University, Shanghai, CHINA,
[2] Human Phenome Institute, Fudan University, Shanghai, CHINA
ydlin@fudan.edu.cn

Abstract

1. Motivation, specific objective

The spectrum of ambient light profoundly affects people's physiological and psychological responses. The widely regarded daylight LEDs are thought to have better effects on people because they have a smoother, fuller spectrum that is more similar to the solar spectrum. Daylight LEDs have been shown to bring about better alertness, sleep intensity, subjective mood, and visual perception. However, it is unknown what characteristics of daylight LEDs lead to their better performance. Therefore, for non-visual effects, this study set up controlled experiments by controlling the variation of spectral parameters to investigate the effects of daylight LEDs and the influencing factors.

2. Methods

In the present study, ordinary LEDs with different circadian stimulus levels were set up for comparison with daylight LEDs. In Experiment 1, high circadian stimulation LEDs with the same circadian stimulus level (melanopic EDI and circadian stimulus, CS) but the different similarity to sunlight were set to compare the cortisol secretion of subjects at different times of the day by hourly saliva sample collection. In Experiment 2, six office lighting of two spectral types (daylight LED and ordinary LED) with different melanopic EDI levels were set up to investigate subjects' performance. Subjective daytime alertness was assessed using the Stanford Sleepiness Scale (SSS), and sleep quality was assessed using the Groningen Sleep Quality Scale (GSQS) and the Consensus Sleep Dairy (CSD) the morning after the light intervention.

3. Results

Experiment 1 showed no significant difference in the change in cortisol concentration between daylight LEDs and the original LED with the same CS value or melanopic EDI at each CCT. Experiment 2 showed that all six lighting conditions improved alertness and sleep quality within the experimentally selected range (melanopic EDI = 197~403 lx, CS value = 0.35~0.43), but there were no significant differences between groups. Regardless of CCT and spectral type, lighting conditions with higher circadian stimulus levels tended to result in higher daytime alertness and better nighttime sleep quality.

4. Conclusions

The present study demonstrates that with similar melanopic EDI (or CS) values, daylight LEDs do no longer lead to greater alertness due to greater similarity to daylight compared to ordinary LEDs. For both the two kinds of spectra, higher circadian stimulus levels tend to have better effects. We conclude that, firstly, higher circadian stimulus levels lead to good non-visual effects. Secondly, as daylight LEDs normally have higher circadian stimulus levels due to the relatively higher blue portion of the spectrum, they leading to greater daytime alertness and nighttime sleep quality in general. This study provides some evidence for the development and application direction of daylight LEDs.

Poster Session 2

Tuesday, September 19, 16:05-17:35

PO130

THE SAME LIGHT, DIFFERENT EFFECTS AT THE SAME TIME: POSITIVE AND NEGATIVE EFFECTS OF THE VISIBLE LIGHT ON THE RETINA

Or, K. H.[1,2]
[1] Private Office of Ophthalmology, Istanbul, TURKEY, [2] Private Office of Ophthalmology, Hamburg, GERMANY
hilmi.or@gmail.com

1. Motivation, specific objective

Light is a non -dispensable basic requirement for seeing. However, it can cause various opposite effects in the retina.

2. Methods

The basic mechanisms of dry age -related macular degeneration (AMD) and the relatively new therapy method of dry AMD compared and discussed with Low Light Therapy (photobiomodulation).

3. Results

In addition to the UV, the cause of the aging changes in the dry AMD is also held responsible for the visible optical spectrum of the light. Low Light Therapy (photobiomodulation) has long been used for therapy for other disciplines in medicine (especially in dermatology). This stimulates the cell function and metabolic activity and sometimes reaches cell regeneration. The same effects can be reached in the macula in dry AMD in particular with wavelengths 590, 660 and 850 nm and the visual function improved.

4. Conclusions

The visible light can have negative and positive effects on the health of the retina that depends on dose and wavelengths. With the dry AMD, the positive effect can be achieved with light in low “dosage” after damage with light throughout life and in some cases at least partly treated.

PO60

COLORIMETRIC CALIBRATION BETWEEN RGB AND LMSR SPACES

Legrand, B., LABAYRADE, R.
Université de Lyon, ENTPE, LTDS, BPMNP, 3 rue Maurice Audin Vaulx-en-Velin (69120), FRANCE
benjamin.legrand@entpe.fr

Abstract

1. Motivation, specific objective

To ensure pedestrian and motorist visibility or to highlight urban public space, public lighting systems are essential. Today, in Europe, a saving-energy policy is applied so current public lighting systems may be replaced in the near future. In order to assess and design future public lighting projects, decision making tools can be developed, based on acquisitions and restitutions of urban night scenes. Indeed, urban night scenes can be evaluated by panels of users in terms of lighting distribution and colors, though visualization systems, without requiring users to be present in the actual scene itself. It will make it possible to use such a process to improve urban lighting installations both for user preferences and power demand. These urban night scenes have a lot of particularities such as a wide luminance range and at the same time mesopic average luminance levels that result in a visual perception ruled by both eye cones and rods.

One way to capture and restitute night urban light scene is to use colorimetric calibration. Colorimetric calibration methods perform transformations between camera color space (RGB) and human eye color space in photopic conditions (XYZ), only when cones are excited. Colorimetric calibration for display devices can be performed in the same way, to compute the RGB values to display, corresponding to XYZ stimulus.

This paper proposes a method to perform colorimetric calibrations of camera or monitor in mesopic conditions. In such conditions, the biological eye color-space is a 4D space defined from response curves of long (L), medium (M) and short (S) cones, and rods (R): LMSR.

2. Methods

A colorimetric transformation between two color spaces relies on some reference points. In the latter we will either consider the transformation required for the acquisition step using the camera, RGB -> LMSR (3D to 4D), or for the restitution step, LMSR -> RGB (4D to 3D) aimed at displaying the stimulus.

For the acquisition, a calibrite ColorChecker (24 cases) and two custom ColorCheckers containing 256 colors each are used are used.

First, all color case spectral reflectances are measured in a specific geometric pose, corresponding to known camera and source positions; the ColorCheckers are then placed, sequentially, under 8 sources whose spectrum has been measured also. Thus, the spectral radiance seen from the camera can be computed. The theorical excitation value of both cones and rods cells are also computed, from the long, medium, short (LMS) cone spectral transmittance curves, and from the rod (R) spectral transmittance curve. In such a way, up to 24 + 256 + 256 = 536 RGB reference points and 536 LMSR corresponding values are obtained for each source, and will be used to estimate the transformation from the RGB camera space (3D) to the LMSR space (4D).

For the restitution, an Eizo CG277 monitor is used. The colors displayed by the monitor are obtained by a combination of R, G, B sampling, with a step of 16 on the color component valu (for instance [32,64,16]). Then spectrum measurements are performed using a spectroradiometer oriented normal to the screen. LMSR values corresponding to the displayed RGB colors can thus be computed, which leads to obtain (256*3 – 2) = 766

reference points (to avoid measuring three times color [0,0,0]) to estimate the transformation from the LMSR (4D) space to the monitor RGB space (3D).

In order to estimate the transformation between a 3D space and a 4D space, first 4 3D-transformations between the RGB 3D space and the 4 all possible 3D subspaces of the LMSR 4D space are estimated:

RGB -> LMS

RGB -> LMR

RGB -> LSR

RGB -> MSR

Each 3D transformation can be estimated either as a linear SVD-based transformation, or as a tetraedric transformation, where the reference points are partitioned into tetrahedrons, each of them in the RGB space corresponding to another tetrahedron in the LMS (or LMR or LSR, or MSR) space. Into a tetrahedron, a linear transformation is performed.

The final L (resp M, S, R) value is computed as average of the 3 L (resp M, S, R) values obtained from the 4 transformations above.

A similar process is performed to estimate the transformation from LMSR (4D) to RGB (3D).

3. Results

Transformation of 3D RGB space to 4D LMSR space: mean relative errors (and standards deviations) for all 8 sources for the SVD method (resp. tetraedric) are as follows (in %): L – 3.52 (3.99); M – 3.57 (3.62); S – 10.2 (19.8); R – 4.39 (6.03) (resp. L – 2.07 (2.47); M – 2.06 (2.25); S – 3.15 (7.50); R – 2.09 (2.54)).

Transformation of 4D LMSR space to 3D RGB: mean relative errors (and standards deviations) for the SVD method (resp. tetraedric) are as follows (in %): R – 4.25 (11.1); G – 4.51 (10.4); B – 5.54 (13.7) (resp. R – 0.658 (1.69); G – 1.21 (4.30); B – 2.45 (7.73)).

4. Conclusions

For both acquisition and restitution steps, tetraedric-based calibration presents more accurate results than SVD-based calibration.

Calibration from a 3D space to a 4D space (acquisition) provides accurate results for both cones and rods component (2.34 % mean relative error on 4 L, M, S, R components).

Calibration from a 4D space to a 3D space (restitution) provides even more accurate results for all RGB components (1.44 % mean relative error on 3 R, G, B components).

In future works, RGB values obtained from the colorimetric calibration from LMSR to RGB will be displayed by the calibrated screen, and emitted spectrums will be measured in order to compute relative errors between desired LMSR and actual screen emitted LMSR. In order to guarantee that the method could be used along the entire process (from acquisition to restitution), a colorimetric calibration between RGB-camera and RGB-screen spaces passing through the LMSR space could also be considered. Eventually, a psycho-visual experiment will be conducted to evaluate the method in terms of human perceptions.

PO137

ON THE QUESTION OF THE UNCERTAINTY OF CIE 1931 COLOR-MATCHING FUNCTIONS

Scums, D.V.
Independent metrological consultant, Minsk, BELARUS
Dmitri.V.Scums@gmail.com

Abstract

For almost a hundred years, the CIE 1931 colorimetric system remaining the backbone of color measurements in science and industry. However, the redefinition of the SI system raises difficult questions about the assessment of the uncertainty of color measurements and their belonging to the sphere of the SI system. In the article discusses various aspects concerning estimating of the uncertainty of CIE color-matching functions. As well as possible ways of its evaluation are proposed.

Motivation

For almost a hundred years, the CIE 1931 Standard Colorimetric Observer and the CIE RGB and XYZ systems based on it have shown amazing success, remaining the backbone of color measurements in science and industry. However, like any deeply rooted technology, it does not always fully meet modern challenges. One such challenge is the calculation of the uncertainty in the colorimetric measurements. Known in 1931 only to a narrow circle of physicists and mathematicians, experts in quantum theory, the concept of uncertainty in our time has become an integral part of any routine measurements.

In the course of analyzing the sources of uncertainty for the CIE color rendering index, the authors faced the issue of estimating the uncertainty of CIE color-matching functions (hereinafter referred as CMF). In search of an answer, we turned to the CIE guidelines CIE 15 and CIE 198. And if the first did not contain answers, then in the second (CIE 198 SP.2), it was directly stated: “Weighting tables such as the CIE color-matching functions contain no uncertainty”.

We do not fully agree with this statement and would like to present our opinion below in the form of following questions arising from this thesis and our reflections on them.

1. Is CIE colorimetry part of the SI system?
2. Can CIE CMF be considered as physical constants that can be included in SI?
3. Can CIE CMF be considered as some sort of scaling factors?
4. Anything that is defined has no uncertainty by definition.
5. How can the uncertainty of the CIE CMF be assessed?

Conclusion

CIE colorimetry can and should be considered as a part of the SI system. CIE 1931 colorimetric functions are not scaling factors and should not claim to be fundamental physical constants. Being a model of a real physical phenomenon, they must have uncertainty, the evaluation of which can and should be the subject of separate studies.

Although in our article we consider only the CIE 1931 system, guided by the same approach, we can raise similar questions to Cone Fundamental Based Photometry. Given that it is seen as a replacement for CIE 1931, as well as its relative novelty and therefore the availability of primary data, it seems important to consider this through the lens of the issues raised in our work.

We also want this article not to be taken as criticism of Wright and Guild (we see far, because we stand on the shoulders of giants) but as an invitation to discussion.

PO141

NEW CALIBRATION STANDARDS AND METHODS FOR RADIOMETRY AND PHOTOMETRY AFTER PHASEOUT OF INCANDESCENT LAMPS

Florian Stuker[1]
[1] Federal Institute of Metrology METAS, Bern-Wabern, SWITZERLAND
florian.stuker@metas.ch

Abstract

1. Motivation

Accurate knowledge of spectral irradiance of optical radiation emitted by artificial and natural light sources is essential in various fields of industrial (UV-curing, disinfection, photovoltaic equipment, general and horticultural lighting, etc.), environmental (solar radiation, ECVs, etc.), medical (sun beds, photobiological treatment, etc.), or scientific (analytical spectroscopy, plasma, etc.) applications. The field of applications for the spectral irradiance measurements has grown dramatically during the last couple of decades due to the market introduction of affordable new-technology spectroradiometers based on array detectors and digital capabilities for in-situ processing of the spectral data. The routine availability of the spectral characteristics of the optical radiation sources is seen as one of the technological enablers for high-quality products, information, and services.

2. Need

For the calibration of spectroradiometers, incandescent lamp-based transfer standards have been used for decades. Selected quartz-tungsten-halogen (QTH) lamps of certain types have been applied to disseminate the spectral irradiance unit in the spectral range from 250 nm to 2500 nm. Their handling simplicity, wide and smooth emission spectrum optimally suited for the applications, good temporal stability and reproducibility yielded excellent transfer standards for the spectral irradiance with the lowest uncertainties possible. The availability of such lamps on the market, also fit for the metrological purpose, however, is diminishing due to the production phaseout following the ban of the incandescent lighting by the EU Commission in 2009. It was followed by a technology change to solid-state-lighting (SSL) products. The spectra of the new replacement lamps based on the SSL technology, however, is restricted to the visible wavelengths. Thus, alternative transfer standards built on new-technology sources with smooth spectra throughout the UV-VIS-NIR spectral range and/or detector-based calibration methods for the spectroradiometers are urgently needed. To address the urgent need to provide replacement sources and alternative procedures for a detector-based transfer of the unit, a joint research project 22IEM05 NEWSTAND within the framework of the European Partnership on Metrology is starting in June 2023. This conference contribution will present research activities planned for the next 3 years within the project.

3. Technical Objectives

The overall objective of the project is to enable the SI-traceable measurement of spectral irradiance from natural and artificial sources of optical radiation in terms on new-technology transfer standard sources and procedures for detector-based dissemination of the unit as well as to develop the metrological infrastructure required for these measurements. The project includes three technical work packages addressing following objectives:

1. To develop new transfer standard sources for spectral irradiance in the ultraviolet-visible-near infrared (UV-VIS-NIR) spectral ranges, built on new-technology products to replace current transfer standards that are based on incandescent lamps. The specific requirements for the spectral irradiance of the new standard sources are: i) well-defined and fit-for-purpose spectral and geometric properties, ii) long-term stability, iii) reproducibility, iv) robustness, and v) compatibility with existing calibration facilities.

As a new approach creating transfer standard sources, wavelength-tuneable narrowband light sources with a sub-nanometre spectral bandwidth will be built as well. The new standard sources shall allow dissemination of the spectral irradiance unit with transfer uncertainties as low as 0.5 % (k = 2).

2. To develop novel methods for enabling detector-based traceability of spectral irradiance measurements as an alternative to the incandescent lamps-based dissemination of the unit. This will involve i) the definition of the minimum requirements for relevant properties of array spectroradiometers to be suitable as transfer standards and selection of the instruments for the work within the project, ii) comprehensive characterisation of the selected instruments for all relevant properties and their calibration with respect to the spectral irradiance responsivity, iii) development of a versatile digital twin model of a transfer standard spectroradiometer that will enable the transfer of the instruments' characterisation and calibration results to the end users' applications and it will also enable to determine associated measurements uncertainties under changing measurement conditions, and iv) elaborate and document the concept needed for the transfer of the calibration results from one spectroradiometer instrument to another.

3. To demonstrate the metrological applicability of the new standard sources and methods, developed in objectives 1 and 2, in spectroradiometric applications involving spectral irradiance measurements in at least 3 end user applications with total uncertainties as low as 1 % (k = 2). This shall be done via interlaboratory comparisons and measurement comparison campaigns involving end user applications from solar radiation measurements, actinic radiometry, photovoltaics, lighting, and colour.

4. To develop good practice guides for using the newly developed transfer standard sources, selection of spectroradiometers as transfer standard instruments and the respective calibration procedures, the use of the digital twin of the calibrated array spectroradiometers allowing to implement the measurement methods and devices developed by the project.

4. Project Consortium

The development and metrological implementation of new-technology calibration standards and new dissemination procedures covering the wide spectral range is a manifold task. Therefore, a consortium including following European National Metrology Institutes (NMIs), Designated Institutes (DI) and companies prepared a joint research project proposal that was successive in the selection process: Physikalisch-Technische Bundesanstalt (PTB), Aalto-korkeakoulusäätiö sr (Aalto), Cesky Metrologicky Institut (CMI), Conservatoire national des arts et métiers (CNAM), Agencia Estatal Consejo Superior de Investigaciones Cientificas (CSIC), Instituto Português da Qualidade, I.P. (IPQ), Laboratoire national de métrologie et d'essais (LNE), AS Metrosert, RISE Research Institutes of Sweden AB, Turkiye Bilimsel ve Teknolojik Arastirma Kurumu (TUBITAK), VSL B.V., Institut für Solarenergieforschung GmbH (ISFH), Gigahertz Optik GmbH, Instrument Systems GmbH, Eidgenössisches Institut für Metrologie METAS, National Physical Laboratory (NPL), Physikalisch-Meterologisches Observatorium Davos/World Radiation Center (PMOD/WRC). The consortium is also open for new partners to join the challenging research project as collaborators.

4. Project Consortium

The joint research project 22IEM05 NEWSTAND "New calibration standards and methods for radiometry and photometry after phaseout of incandescent lamps" has received funding from the European Partnership on Metrology, co-financed by the European Union's Horizon Europe Research and Innovation Program and by the Participating States.

PO26

A CASE STUDY OF TUNABLE WHITE LED LIGHTING WITH NETWORKED LIGHTING CONTROLS

Miller, N.J.
[1] Pacific Northwest National Laboratory, Portland OR, USA
Naomi.miller@PNNL.gov

Abstract

1. Motivation, specific objective

Emory University and the Georgia Institute of Technology (Georgia Tech) partnered to create a Cognitive Empowerment Program (CEP) facility in northeast Atlanta, USA. Together with the funders, they are building a program to help individuals experiencing mild cognitive impairment (MCI) to maintain their physical and cognitive health and independence for as long as possible. In addition to applying effective strategies and therapies, the two research groups are investigating the responses of the MCI patients to treatments that involve acoustical conditions, exercise and movement, and lighting changes that may support retention or relearning of skills. Care partners and family members receive support and instruction to improve home and work life, promoting joy, purpose, and wellness in the family groups.

The goals for the lighting and controls were to provide a visually comfortable, bright and cheerful environment for the MCI members, supportive of visual tasks, therapeutic movement, interviewing, teaching, evaluation, treatments, and even classes in food preparation. Lighting flexibility was important because many spaces are used for a variety of activities and there were potential plans to offer programing in the evening hours. In addition, knowing that bright days and dark nights support physical, cognitive, and psychological health, the lighting was designed to be tunable for different colors and intensities of white light to support alertness during the day without being too stimulating in the evening to support sleep quality at night. Controls were essential to providing the flexibility and programmability of individual spaces and the whole floor together, with the added code-compliant bonus of energy efficiency functions to dim or switch off lighting when not needed, and measurement and reporting of lighting system operation and usage for research.

The lighting system uses tunable-white light-emitting diodes (LEDs), employing luminaires with both warm- and cool-color emitters that can be dimmed separately to produce any white correlated color temperature (CCT) between 2700 and 6500 K. All luminaires were dimmable to achieve subdued or lively surroundings for different treatments, times of day, and moods. A central networked digital control system was employed to allow tuning of multiple spaces together (for example, bright, cool morning light could be programmed for extra stimulation, or lighting in all spaces at the end of the day could be reduced in both light output and CCT to promote relaxation and not interfere with the melatonin cycle of occupants). Almost all spaces were equipped with individual room control of dimming and color temperature with touch screens to allow users to tune the lighting as desired, but each room's controls could also be specially programmed through the server in case the research staff were investigating the effects of lighting settings on activities such as learning. The server incorporates a timeclock and can send signals to switch off all lighting after occupancy hours or enable occupancy sensors to control the lighting.

The motivation for the research was originally to document the effect of lighting and controls modifications on MCI patients and the staff. When it became clear the networked system was behaving in unpredictable ways, the motivation morphed into a study of what went wrong, and why, and how to avoid similar problems with similar systems in the future.

2. Methods

The observation and evaluation of the project took place over a 3 year period, with the author's research institution participating in design sessions, reviewing design and construction documents, and attending on-site visits. All activities and communications among the design professionals, the installers, the controls manufacturer, and the lighting agency controls experts were shared through email and video conferencing calls. A record of product and site performance issues and resolutions were recorded and tracked over the 2.5 years it took to get the system working as intended.

3. Results

The jobsite suffered a prolonged set of lighting inconsistencies and controls quandaries, which were resolved by technicians and manufacturer experts, and unfortunately recurred days, weeks, or months later. Diagnosing the problems required iterative upgrades to LED boards, drivers, load controllers, server software and firmware upgrades, and changeouts of user interfaces and sensors.

4. Conclusions

This is a single case study, but together with similar projects tracked by the author's research institution over 5 to 7 years, it is clear its problems are by no means unique. There is an extensive list of lessons learned on this smart lighting control system, starting with the need to keep lighting controls simple and localized. A common vocabulary for the system architecture is sorely needed, as is standardization and interoperability on components and communication protocols. These networked systems offer great promise for energy savings and productivity improvements and asset tracking. However, before widespread successful adoption can happen, the lighting and controls industry must consider the long-term needs and frustrations of specifiers, clients, end-users, and facility managers.

PO32

LIMITATIONS IN CEILING AND WALL ILLUMINATION FOR GENERAL LIGHTING IN INTERIORS

Pracki, P. [1], Komorzycka, P.[1]
[1] Warsaw University of Technology, Electrical Power Engineering Institute, Lighting Technology Division, Warsaw, POLAND
piotr.pracki@pw.edu.pl

Abstract

1. Motivation, specific objective

For the practical evaluation of the luminance distribution in interiors, the illuminance and reflectance of the ceiling and walls are considered. Lighting requirements for the average illuminances on the ceiling (EC) and walls (EW) depend on the average illuminance on task area (E). In the standard EN 12464-1:2021, the requirements for EC and EW were moved from the main text to tables. In this form, the requirements are more practical and emphasize the need to analyze and meet them when designing interior lighting. The main factors influencing the EC and EW levels are the luminous intensity distribution and layout of luminaires, and interior size and reflectance. The motivation to undertake the study was the willingness to check the degree of limitations in obtaining EC and EW levels and determine the luminaire types for which meeting the requirements for EC and EW is limited.

The specific objective of the study was to determine: (1) the obtained the EC and EW levels, (2) the limitations in meeting the EC and EW requirements, (3) the luminaires' luminous intensity distribution limitations in meeting the EC and EW requirements, and (4) the visual lightness and apparent brightness for general lighting in interiors.

2. Methods

The realization of the objective was based on simulation study in model interior lighting situations. Models of interiors, lighting systems and calculations were made in a verified software, and the results were analyzed in the Statistica package.

In order to consider various general lighting situations, the following assumptions were taken:

- room size: 3 room indices: 1.5 (relatively small room), 3.0 (moderate room), 4.5 (relatively large room),

- room reflectance: 3 sets: (0.7 for ceiling, 0.5 for walls, 0.2 for floor), (0.7 for ceiling, 0.5 for walls, 0.3 for floor) and (0.7 for ceiling, 0.7 for walls, 0.2 for floor),

- luminaire: 4 lighting classes: direct lighting, semi-direct lighting, direct-indirect lighting, semi-indirect lighting,

- luminaire: 4 downward luminous intensity distributions (DLID): the widest distribution, relatively wide distribution, relatively narrow distribution, the narrowest distribution,

- layout: 3 spacing-to-height ratios: 0.5 (small spacing), 1.0 (moderate spacing), 1.5 (large spacing).

There were 432 lighting situations considered for each E level considered (in lx): 100 – 150 – 200 – 300 – 500 – 750 – 1000. The result analysis covered the EC and EW values first, but also the luminances of the ceiling LC and walls LW, and the mean ambient illuminances EA for the interiors.

3. Results

Depending on E level, the following EC and EW levels were available:

- for E=100 lx, EC between 15 lx and 150 lx, EW between 30 lx and 50 lx,
- for E=150 lx, EC between 20 lx and 200 lx, EW between 30 lx and 100 lx,
- for E=200 lx, EC between 30 lx and 300 lx, EW between 50 lx and 100 lx,
- for E=300 lx, EC between 30 lx and 300 lx, EW between 75 lx and 200 lx,
- for E=500 lx, EC between 75 lx and 750 lx, EW between 100 lx and 300 lx,
- for E=750 lx, EC between 100 lx and 1000 lx, EW between 200 lx and 500 lx,
- for E=1000 lx, EC between 150 lx and 1500 lx, EW between 200 lx and 500 lx.

Depending on E level, the limitations in meeting the EC or/and EW requirements were as follows:

- for E=100 lx, EC (30 lx) requirement was not met in 23.6% of cases, EW (50 lx) requirement was not met in 44.2% of cases, and both requirements were not met in 16.4% of cases,
- for E=150 lx, EC (30 lx) requirement was not met in 4.6% of cases, EW (50 lx) requirement was not met in 1.4% of cases, and both requirements were not met in 0.9% of cases,
- for E=200 lx, EC (50 lx) requirement was not met in 15.0% of cases, EW (75 lx) requirement was not met in 7.9% of cases, and both requirements were not met in 4.4% of cases,
- for E=300 lx, EC (75 lx) requirement was not met in 15.3% of cases, EW (100 lx) requirement was not met in 1.4% of cases, and both requirements were not met in 1.2% of cases,
- for E=500 lx, EC (100 lx) requirement was not met in 5.5% of cases, EW (150 lx) requirement was not met in 0.2% of cases, and both requirements were not met also in 0.2% of cases.

For E=750 lx and E=1000 lx, the EC (100 lx) and EW (150 lx) requirements were met for all cases.

The direct lighting limited meeting the EC requirement mainly for E=100 lx, also for E=200 lx and E=300 lx. The luminaires with the narrowest DLID limited meeting the EW requirement mainly for E=100 lx.

On the basis of the determined EC and EW levels, the LC and LW levels were calculated for the E levels and reflectance sets considered. Changes in the ceiling and wall luminance levels as a result of increasing the floor reflectance from 0.2 to 0.3 or the wall reflectance from 0.5 to 0.7 were assessed. The results were commented in terms of the visual lightness in the interiors.

On the basis of the determined EC and EW levels, the EA and the EA/E ratio were calculated for the E levels. The results were commented in terms of the apparent brightness in the interiors.

4. Conclusions

Typical general lighting solutions in interiors encounter limitations in the level of average illuminances on the ceiling and walls. However, for the E levels considered, wide ranges of EC are obtained and the achievement of EW levels is significantly limited.

The normative EC and EW requirements are a limitation for some direct lighting solutions and luminaires with narrow downward luminous intensity distributions, at the E levels up to 500 lux.

The research results have cognitive and practical significance in the field of electric lighting in interiors.

PO36

STUDY OF DAYLIGHT HEALING FOR LONG-TERM QUARANTINED OCCUPANTS DURING THE COVID-19 PANDEMIC

Shao, R.D.[1,3], Cao，Y.X.[1], Hao, L.X.[1,2]
[1] College of Architecture and Urban Planning, Tongji University, Shanghai, CHINA, [2] Key Laboratory of Ecology and Energy-saving Study of Dense Habitat (Tongji University), Ministry of Education, Shanghai, CHINA; [3] Shanghai Tongji Architectural and Interior Design Engineering Co., Shanghai, CHINA.
haoluoxi@tongji.edu.cn

Abstract

1. Motivation, specific objective

During the COVID-19 pandemic (2020-2023), people experienced long-term quarantine which has a substantial impact on their physical and mental health, while light has the notable impact on sleep and moods. The study collected data from 1118 subjects during the epidemic through questionnaires to find the sleep and mood problems and lighting requirements of the residents. It also studied the sleep and mood improvement effects by daylight on the subjects in Shanghai to provide a feasible light healing solution for the long-term quarantined occupants.

2. Methods

33 subjects (age 48.7±1.59 years, 17 males and 16 females) were recruited to conduct a continuous daylight healing experiment for 2 weeks during the quarantined period from April to May 2022 in Shanghai. The daylight experiment required subjects to receive at least one hour of cumulative daylight exposure at a window or balcony at a fixed time during the day and warm, low-intensity light at night before bedtime. Data on vertical eye illumination (E_{cor}), melanopic EDI, Pittsburgh Sleep Quality scale (PSQI), sleep log and Self-Rating Depression Scale (SDS) and Self-Rating Anxiety Scale (SAS) were collected to comprehensively evaluate the subjects' sleep and mood. Through measurement and simplified modelling, the intensity and timing were quantitatively analyzed to find out if the current level of lighting conditions in residential buildings of Shanghai can meet the needs of rhythm, sleep and mood, and if there are adverse light stimuli as the basis for optimization.

3. Results

The results showed that among the sleep indicators, there was a gradual increasing trend in the sleep duration from day 1, day 8 to day 14, with a significant decrease on day 14 relative to day 8 ($p<0.05$), and a decreasing trend in the number of awakenings, sleep latency, awakening time, and bed departure time, and also with an increase in sleep efficiency. SDS and SAS scores showed a decreasing trend with significant differences ($p<0.05$) in the mean values at baseline, week 1, and week 2 during the experiment, demonstrating that light changes contribute to mood regulation, while analysis of the scores on day 1, 8, and 15 showed that with the accumulation of daylight exposure, overall anxiety and depression scores had a significant downward trend ($p<0.05$).

4. Conclusions

Firstly, the effect of two weeks of one-hour daylight exposure per day on the sleep and circadian rhythm was verified. Daily exposure to natural light helped to improve the sleep quality and sleep duration of the long-term quarantined subjects, and reduced the number of wake-ups, sleep latency, wake-up time, and bed departure time. Secondly, a comprehensive evaluation of sleep quality and emotional state dimensions was conducted to demonstrate the improvement effect of daylight on human stress state in long-term quarantine conditions. Finally, daylight healing strategies are provided for the long-term quarantined occupants.

PO37

EFFECTS OF LIGHT WITH THE SAME CORRELATED COLOUR TEMPERATURE BUT DIFFERENT COLOUR OF APPEARANCE ON THE IMPRESSION OF A SPACE

Shinohara, N.[1], Ito, D.[2], Nakaso, M.[3], Kaiho, K.[3],
[1] Tokai University, Kanagawa, JAPAN, [2] Nippon Institute of Technology, Saitama, JAPAN,[3] Nikken Sekkei, Tokyo, JAPAN,
n_shinohara@tsc.u-tokai.ac.jp

Abstract

1. Motivation, specific objective

Colour of light is generally described by the correlated colour temperature (CCT). However, light sources with the same colour temperature may show different colour of light. This is due to the chromaticity shift from the Planckian locus duv. It has been pointed out that the favourable CCT differs depending on human behaviour. Even correlate colour temperatures that were evaluated favourable for a human behaviour, may not be evaluated favourable for that behaviour depending on the duv. In addition, it has been shown that the duv influences on the evaluation of spatial brightness. By using the light with duv, which is perceived as favourable for a human behaviour and increases spatial brightness, it is possible to achieve both comfort and energy conservation.

The purpose of this study is to identify the appropriate light colour (including duv as well as CCT) and illuminance for lighting design based on human behaviour. The difference in the evaluation of different duvs for different human behaviours under the same CCT and illuminance conditions are examined by subjective experiments using models.

2. Methods

The experiment was conducted in October 2022. Two boxes were used in this experiment. One is the reference box and the other is the comparison box. The boxes had a size of 600mm(W) x 600mm(D) x 600mm(H). Four LED lamps which can adjust a colour and illuminance of the light are installed on the ceiling of each box. Three achromatic three-dimensional objects were placed inside each box as a visual object. For the reference box, four conditions, two colour temperatures (3000K and 5000K) and two illuminances (250lx and 500lx) were prepared. The duv of all conditions were zero. The CCT of the comparison box was set to the same as the CCT of the reference box. The duv of the comparison box was set from -0.03 to +0.03 in increments of 0.01, resulting in 7 conditions. The illuminance of the comparison box was dimed by the subject to the same brightness as a reference box. Dimming started at half (increasing dimming) and twice (decreasing dimming) the reference box illuminance. A total of the comparison box conditions are 56 conditions, two colour temperatures, four illuminances (2×2) and seven duvs.

The experiment was conducted in a dark room. First, the lights in both box is a switched on after ten seconds with the lights off, and then the subject compared the comparison box with the reference box for 10 seconds. The subject used a tablet to dim the lighting in the comparison box so that the brightness of the visual objects in the comparison box was the same as the brightness of the visual objects in the reference box. After adjusting the brightness, the subject assumed the inside of the box to be a concentration space or a relaxation space, and evaluated each in terms of acceptability, favourability and naturalness. The subjects also indicated whether they preferred the reference box or the comparison box. Experimental conditions were presented randomly for each subject. Twenty-four subjects in their twenties with normal colour visions participated.

3. Results

Calibration curves for dimming rate and illuminance were prepared for all conditions in advance.

In the case of CCT of 3000K, average illuminance of the comparison box adjusted by the twenty-four subjects peaked at the duv of 0.01. Statistical tests show that there was no significant difference in the dimmed illuminance between duv of zero and +0.01, however, it shows that dimmed illuminance for duv of -0.01, -0.02 and -0.03 were significantly lower than that for duv of +0.01. When duv was less than zero, the illuminance of the comparison box was about 20% lower than that of the reference box.

In the case of CCT of 5000K, average illuminance of the comparison box adjusted by the subjects was higher the higher the duv. The dimmed illuminance with duv of less than zero was significantly lower than that with duv more than zero. The illuminance with duv of less than zero of the comparison box was about 10% lower than that of the reference box.

For the concentration space, the highest acceptability and the highest favourability were shown at the duv of zero for all conditions. The statistical test results show that both acceptability and favourability with duv of less than zero were significantly higher than those with duv of more than zero, in the case of CCT of 3000K. In the case of CCT of 5000K, since only the space with duv of +0.03 significantly lower than the other conditions in both acceptability and favourability.

For the relaxation space, in the case of CCT of 3000K, the evaluation of acceptability and favourability were peaked at the duv of zero. The statistical test results show that in the case of CCT of 3000K, acceptability and favourability with duv of -0.03, +0.02, and +0.03 were significantly lower than that with duv of zero, so duv of from -0.02 to +0.01 were considered appropriate. In the case of CCT of 5000K, there was no significant difference in both acceptability and favourability between all conditions. About 20% of subjects evaluated the space with duv of zero unacceptable and about 40% of subjects evaluated it unfavourable. It is considered that the case of CCT of 5000K was not suitable for a relaxation space.

4. Conclusions

This study shows that evaluation of spatial brightness and impression were both affected by the duv. It is considered that light with the duv of less than zero could reduce the illuminance by approximately 10-20% compared with light with the duv of zero. The ranges of preferred CCT and duv varied depending on the human behaviour. Not only CCT but also duv should be taken into account when preferability of light colour is evaluated depending on human behaviour.

PO42

SIMULATION OF ENERGY CONSUMPTION IN BUILDINGS WITH SMART BLINDS

Wu, Y.[1]; Qiu, R.[2]; Kaempf, J.H.[3]; Scartezzini, J-L.[4], Hao, L.[1];
[1] College of Architecture and Urban Planning, Tongji University, Shanghai 200092, CHINA, [2] SDIC Power Holdings Co., Ltd, Beijing 100032, CHINA, [3] Idiap Research Institute, CH-1920, Martigny, SWITZERLAND, [4] Solar Energy and Building Physics Laboratory (LESO-PB), École Polytechnique fédérale de Lausanne (EPFL), CH-1015, Lausanne, SWITZERLAND
yujie.wu@tongji.edu.cn

1. Motivation

Modern buildings are designed with large windows and glazed facades to allow sufficient daylight penetration and good view outwards; however, excessive solar gains contribute to the discomfort glare and overheating issues in office buildings, which lower the productivity of occupants and increase the cooling energy consumption during summer. Studies have shown that occupants commonly keep blinds closed during daytime and their interaction frequency is low with blinds.

2. Methods

Smart blinds are designed to adjust shading to the optimal position according to different sky conditions, delivering visual comfort daylight in office buildings. They can potentially address the issues of discomfort glare for occupants and reduce the energy demand for cooling during the summer and heating during the winter. Therefore, understanding the role of smart blinds from both occupant comfort as well as energy efficiency would be beneficial and helpful to their application.

The target of this project is to understand the behavior of smart blinds and estimate the savings in cooling, heating and lighting energy consumption in office buildings in Switzerland. The annual weather data and the Energy Plus software was employed to assess its climate impact following the direction of Energy Strategy.

3. Results

Results show that the utilization of smart blinds can lead to excellent visual comfort with moderate total energy use and very low lighting and cooling consumption. Meanwhile, it requires low heating and cooling capacity and more fully exploits the capacity during operation. After comparison of different scenarios, the scenario ‘45 degree’ has the highest total end use, followed by the scenario ‘smart blinds’. The scenario ‘smart blinds’ has the highest heating consumption and very low cooling consumption. Besides, the lighting consumptions stay unchanged since the solar injection is not changed in the simulation.

PO48

OFFICE LIGHTING SMART CONTROLS BASED ON USER REQUIREMENTS

Campano, M.A.[1], Acosta, I.[1], Domínguez-Amarillo, S.[1], Bustamante, P.[1]
[1] Universidad de Sevilla, Seville, SPAIN
mcampano@us.es

Abstract

1. Motivation, specific objective

This study evaluates three hypotheses for intelligent control of electric lighting using novel dynamic daylight metrics, which quantify the energy savings achieved based on user requirements, identifying optimal times for dimming or switching off electric lighting using a light sensor or scheduling algorithm. The novelty of this work is based on:

- The proposed smart controls do not require any sensor inside the room. Two of them use an exterior illuminance-meter and a pyranometer to measure the ratio between diffuse and global irradiance, which defines the sky conditions. The third one employs minimum illuminance algorithms to determine the minimum luminous flux of the luminaires under overcast sky conditions.
- Unlike most literature on lighting smart controls, this study incorporates variations in illuminance requirements and occupancy hours during the assessment.

2. Methods

The calculation protocol is established to clarify the methodology's procedures that lead to quantifying the energy efficiency provided by the studied lighting smart controls. The first step involves defining the lighting smart controls and dynamic metrics that describe the on/off or dimming behaviour of each system. Next, the simulation model is used for quantifying energy savings, and other calculation parameters, such as lighting fixture design and user requirements, are defined. Simultaneously, a validation procedure confirms the accuracy of the calculation program that determines the dynamic metrics in the simulation model, using a test room under real sky conditions.

2.1 Definition of lighting smart controls

Three innovative lighting control systems are proposed:

- System A: with a DALI system controlled by an overcast daylight illuminance algorithm.
- System B: employs a DALI controller with a pyranometer and an external illuminance-meter capable of switching the power supply.
- System C like System B but with the ability to dim the power supply.

These systems were chosen based on two criteria:

- They do not require indoor sensors in the room as these devices are often not adequately positioned due to operational constraints.
- The energy savings provided by the proposed systems in electric lighting must be calculated using the existing dynamic daylight metrics.

2.2 Room model

The energy efficiency of the proposed smart controls is calculated using the lighting simulation software *DaySim 3.1*. The model consists of a virtual space with a height of 3.00 m and variable depth (3-6-9 m), with inner surfaces having varying reflectance. The window-to-wall ratio is 30-60-90%, and they are oriented to the north to avoid direct sunlight. The study is conducted in two locations, London (UK) and Madrid (Spain).

2.3 User requirements

Two illuminance thresholds:

- 500 lx, a standard value for offices.
- 250 lx, usual for medium visual effort tasks.

Two occupancy time frames:

- A full-time working schedule from 8:00 am to 6:00 pm.
- A shorter schedule from 8:00 am to 2:00 pm, representing typical short-time working hours.

2.4 Calculation metrics

- Daylight Autonomy (DA): percentage of the year when the minimum illuminance requirement is met by daylight alone during a specific occupancy period.
- Continuous Daylight Autonomy (DA_{con}): percentage of the year when a certain illuminance requirement is met by daylight alone, giving partial credit linearly to the values below the defined threshold.
- Overcast Daylight Autonomy (Da_o): percentage of the occupied time during which the illuminance requirement is met by daylight alone under overcast sky conditions, typically the worst-case scenario.

3. Results

According to the room geometry analysis, it was found that smart control A is only suitable for shallow rooms with large openings. Smart control B resulted in a significant reduction in energy consumption compared to control A for deep rooms, with an increase of up to 41% for rooms 6 m deep and 24% for deeper spaces. Control C performed better for DA_{con} in deep rooms compared to systems A and B, with an absolute increase in energy savings of between 66% and 84% for rooms 6 m deep and between 32% and 78% for rooms 9 m deep.

Based on the room reflectance analysis, dark rooms with small windows require a smart control type C, while controls A and B are not suitable for these scenarios. Control A is not recommended for rooms with low reflectance except for spaces with large windows and an independent control of the luminaire lines.

For locations with predominantly overcast skies, the energy savings promoted by the lighting smart controls proposed are similar in the area near the facade but diverge in the back of the room.

The analysis of user requirements showed that mainly cloudy skies have no noticeable influence on the performance of the studied smart controls. However, in locations with mainly clear skies, full-time schedules promote an absolute increase in energy savings of up to 15% compared to short-time schedules, irrespective of the illuminance threshold. The illuminance threshold had a remarkable influence on the performance of the smart controls analysed, which was almost inversely proportional to the window size.

Finally, based on the energy efficiency provided, smart control C was an optimal solution for deep rooms to reduce energy consumption in locations with mainly clear sky conditions. System B and C could be considered appropriate solutions for rooms with depths of 6 and 3 m, respectively. There was no noticeable difference between a smart system that controls two or three luminaire lines, so it is advisable to promote the independent control of the lighting fixtures.

4. Conclusions

Simulation results indicate that user behaviour and illuminance requirements significantly impact energy consumption of electric lighting, particularly in locations with clear sky conditions. This suggests that user requirements are crucial in determining the suitability of smart controls based on various scenarios. The study shows that smart controls without illuminance-meter feedback (control A) are only suitable for shallow rooms with low requirements, whereas dark, deep rooms require a complex dimming system managed by illuminance-meters located outside, which can regulate the luminous flux of the luminaires. Therefore, based on the study's results, it can be concluded that the widespread adoption of these systems in building lighting design is desirable, particularly for office buildings.

PO49

METRICS AND MONITORING OF THE NON-VISUAL EFFECTS OF LIGHT INDOORS: A SYSTEMATIC REVIEW

Castro, A.A.S.[1], Amorim, C.N.D.[1]
[1] University of Brasília, Brasília, BRAZIL
adrianasekeff@gmail.com

Abstract

1. Motivation, specific objective

Light is defined by the International Commission on Illumination (CIE) as "any electromagnetic radiation that can create a visual sensation by directly stimulating the retinal photoreceptors of the visual system". Furthermore, it can have biological effects that "powerfully regulate health, performance, and well-being". After the discovery of a new photoreceptor in the human retina, called intrinsically photoreceptive retinal ganglion cells (ipRGCs), in 2002, new standards for evaluating illumination began to be incorporated. The non-visual effects of light play a critical role in synchronizing human circadian rhythms with the 24-hour light/dark cycle of the local environment, making studies in indoor environments necessary to ensure the health and well-being of occupants in built spaces. As the term "metric" refers to a combination of representative measurements, dimensions, and conditions at a given scale, lighting metrics in indoor environments allow the evaluation of the luminous performance of a space. However, it is necessary reach consensus about the best metric, or combination of existing metrics, to evaluate the type of lighting proposed, which may be daylight with or without the complement of artificial lighting. For this research, the objective was to conduct a systematic literature review of the metrics regarding the monitoring of the non-visual effect of indoor lighting. This article is part of the theoretical framework of a doctoral thesis research.

2. Methods

This research is a systematic literature review of articles found in Scopus and Web of Science, both of which have a wide range of multidisciplinary and international collections. The following keywords were used: metric, monitoring, measurement, non-visual effect, and circadian light*. Six combinations of keywords were used, resulting in six search strings across the two selected databases. In Scopus, the search was conducted in the search “within article title, abstract, keywords” mode. In Web of Science, searches were conducted in the “all fields” mode, allowing keywords to be present in any part of the content searched. As a basic prerequisite for the standard search, the following were chosen: articles in journals; English language; and, publications between the years 2017 to 2022.

3. Results

The Melanopic Equivalent Lux (EML), Circadian Stimulus (CS), and Melanopic Equivalent Daylight Illuminance (m-EDI) are currently the most commonly used metrics. The teams that developed these metrics have also developed calculators to facilitate their application. Despite the availability of these commonly used metrics, there is still ongoing research for new calculations and possible new metrics. In terms of monitoring, there is currently no standard model to follow, but the research has shown a wide variety of combinations and tests for measuring the collected data, as well as the discussion of adequate calibration for capturing data. Expensive equipment such as spectrometers, HDR cameras, wearable equipment (such as bottoms, glasses, and watches), and fixed sensors in both real and laboratory environments have been used for monitoring. However, research is being conducted to create lighter, smaller, and more affordable devices. Computer simulation for non-visual effects, including Lark and ALFA, has been used to test the reliability of measured data, which is typically compared with in-situ measurements. There is currently no consensus on the form of data validation, but certifications such as WELL, and guidelines from important research groups in the field of non-visual effects of lighting are available. The article shows that daylight is the main source for obtaining better results. Nevertheless, non-visual effects

of lighting are a multidisciplinary field, in which there is plenty of room for further research to achieve greater reliability in measuring and monitoring. This will ensure that users receive the necessary amount of circadian stimulation in indoor spaces. In the future, the findings can be better applied and diffused among building construction practitioners to produce spaces with lighting centered on the user needs, both in terms of visual and non-visual effects.

4. Conclusions

The systematic literature review revealed that during the period from 2017 to 2022, the EML, CS, and m-EDI metrics were the most widely used and established in the studies analysed. However, regarding monitoring indoor spaces, there is still no established model, indicating a vast field of research yet to be explored that will lead to further advancements, not only on the occupants' health but also the development of accessible guidelines for practitioners to incorporate non-visual effects in projects. The researched articles present studies and applications on the use of metrics and monitoring, which can be correlated with other aspects related to health, such as integrative lighting, and sustainability, particularly energy efficiency. In terms of integrative lighting, these studies provide a foundation for achieving human-centric lighting results, while with respect to energy efficiency, the studies contribute to a discussion that goes beyond consumption analysis to consider visual effects. This opens up new avenues for exploring environments that, due to a lack or low amount of natural lighting, do not achieve "circadian entrainment," thereby making it necessary to increase light intensity, resulting in higher energy consumption. The present theme generates positive results in the construction of healthy and sustainable spaces.

PO52

PERCEPTUAL METRICS FOR LIGHT QUALITY IN SPATIAL ENVIRONMENTS

Enger J.[1], Wendin, K.[2,3] and Hiller, C.[4]
[1] University of Arts, Crafts and Design, Sweden, [2] Kristianstad University, SWEDEN, [3] University of Copenhagen, Denmark, [4] RISE – Research Institutes of SWEDEN
johanna.enger@konstfack.se

Abstract

1. Motivation, specific objective

Sight is the sense that gives us visual information about the world around us, and light is a prerequisite for this process. Light radiation can be measured physically with precision, but light as the experience created when light rays strike the retina of the eye is sensual, and thus both subjective, relative and complex. All the light we see is reflected from surfaces, unless you look directly into a light source. The properties of surfaces, their colour and texture in combination with the properties of the light source and the distribution of light, is what provides visual information about the room.

The established methods available to assess light quality in spatial environments are based on physical measurements, and thus insufficient as tools to capture perceived values. A consequence is that many lighting environments have poor perceived light quality, even though planned in accordance with recommendations.

With the aim to capture the perceived values, methods and a vocabulary for perceived light quality has been developed in an interdisciplinary research project that has been ongoing since 2016. The method presented here is based on two typologies for spatial environments, one for lighting principles that contain different varieties of evenly distributed and varied light, and one for achromatic colouring that builds different degrees of reflectance and contrast. A combination of the two typologies allows a systematic investigation of how the experience of a light environment changes in relation to light distribution and colour settings, which are decisive factors for perceived differences in contrast and also light level. Words describing perceived light quality have been collected in workshops with members of the lighting industry, and divided into the categories *Experience of the Room*, *Experience of the Light* and *Experience of the Shadows*. The vocabulary and the typologies have been refined through repeated pilot studies to the version that has been used in the study which is presented here.

We have applied methods from Sensory science, which is a well-established discipline originally developed in the beverage and food industries. The analytical sensory analysis leaves out personal preferences and the human senses are used as a measuring instrument. A panel of assessors is trained before the study to agree on consistent definitions of the words they are to assess in relation to the quality being assessed. Another method commonly used method, for e.g. psychological measures, is assessments with semantic differential rating scales. In this project we have used unipolar rating scales for assessments, since the word collection had no clear division between antonyms. In this second method the subjects did not undergo any training before the studies, meaning that the assessments were based on their individual interpretation of the words.

The specific objective for the study was to examine the general validity of the collection of words for perceived light quality in relation to a set of spatial environments designed according to the typologies for light distribution and colour contrast. Two different methods were applied in the study: common unipolar semantic rating scales and the analytical sensory analysis.

2. Methods

A selection of the typologies was combined and applied to 14 physical scale models with identical proportions and interior features. Five different light distributions were represented and combined with interior colour settings ranging from minimum to maximum reflectance, and from low to extreme contrast. Assessments were made with questionnaires containing 38 descriptive words divided in the categories described above, along with assessments for perceived contrast and perceived light level.

For the sensory analysis a panel of 8 people assessed the scale models in randomized order and in triplicates. A different group of non-trained subjects assessed the scale models in randomized order. with differential rating scales. This group consisted of 25 individuals with varying professional backgrounds in ages ranging from 23-86 years.

Lux levels were measured in each model and the achromatic colour setting specified with NCS codes.

3. Results

The results from both methods are generally surprisingly consistent, also compared with previously conducted pilot studies. An analysis shows that the words are distributed according to a clear pattern, where the type of light distribution and the degree of contrast determine which words are used.

For example, are words such as *Uniform* and *Monotonous* are used to describe the experience of the room in a white scale model with even light. The light is accordingly described as *Even*, but also *Flat* and *Clear*, whereas the shadows are *Soft* and *Diffuse*.

A scale model with a varied light and a contrasty middle-grey colour setting was described with words like *Varied*, *Spacious*, *Has depth* (the room), *Distinct*, *Varied* and *Descriptive* (the light), and *Dark*, *Descriptive* and *Distinct* (the shadows).

And as a third example: in a scale model with the same colour setting as in the second example but with even light, the room is again perceived as *Varied*, *Spacious*, and that it *Has depth,* which suggests that the experience of a room is created by combination of light and colour, and the amount of contrast. The light was on the other hand in this case was described as *Soft*, *Mild* and *Clear*, and the shadows as *Soft* and *Diffuse*.

4. Conclusions

The unambiguity in the outcome of this study is promising, taken together with the results from previous pilot studies, which in all have included over 100 individual assessments. It suggests that the collection of words has the potential to serve as a basis for a vocabulary for perceived light quality in spatial environments.

The collection of words we have used in the studies is taken from the informal terminology commonly used by practitioners to describe perceived light quality. The results indicate that the words are generally comprehensible and can be used for assessments even by lay people.

A future development of the vocabulary could be used both in practice and research, for planning, specifications and evaluations of light environments, as well as in comparison with both physical measurements, energy use, and assessments of experienced atmosphere and emotional response.

PO55

A PILOT TEST OF DAYLIGHTING AND ELECTRIC LIGHTING DISTRIBUTION TO ADDRESS VISUAL AND NON-VISUAL REQUIREMENTS

Biju, P.[1], Ståhl, R.[1], Mattsson, P.[1], Gentile, N[1]
[1] Lund University, Lund, SWEDEN
niko.gentile@ebd.lth.se

Abstract

1. Motivation, specific objective

Growing knowledge in the field of non-visual (circadian) effects of light has raised interest on how lighting can promote circadian entrainment. This knowledge is translating into practice. Circadian design metrics such as melanopic equivalent daylight illuminance (mEDI) are today adopted, and target values have been proposed.

While traditional lighting design focuses on adequate horizontal illumination to meet the visual requirements in task areas, circadian lighting design requires the right light at the right time measured vertically at eye position. To meet the "vertical" melanopic illuminance requirements, previous research has found that the horizontal illuminance from electric lighting might be as much as three times higher than stated in lighting design criteria. This poses a challenge with regards to building energy use. Today, integrative lighting systems are normally designed considering rooms as "black-boxes" and using a traditional design of light fixtures.

In order to reach both the visual and the non-visual targets in an energy-efficient way, the current designs for electric integrative lighting, i.e., lighting sustaining circadian entrainment, should a) include daylighting and b) re-think how electric lighting is designed.

The objective of this work, which should be seen as a pilot study, is to test different spatial light distributions of electric lighting in combination with daylighting to meet both visual and non-visual targets in an energy efficient way. Specifically, the study seeks to find the optimal light distributions. The study is currently ongoing and expected results are presented in this project.

2. Methods

Two identical side lit individual office mock-ups are used as test rooms (2.7 m width x 4.0 m deep, about 20% Glazing-To-Wall Ratio with South facing window). The rooms are equipped with 4000 K LED lighting providing 500 lx on the work desk but having different spatial light distribution. The latter is measured via ambient illuminance, as defined by EN1464-1:2021, and it is 250 lx in one case (achieved with downward spotlights), and 500 lx in the other (achieved with direct/indirect pendants). Identical tests will be repeated under electric lighting and mixed daylight/electric lighting conditions.

Ten subjects will be divided into five groups of two to experience the four conditions of 1) electric lighting, lower ambient illuminance, 2) electric lighting, higher ambient illuminance, 3) daylighting and electric lighting, lower ambient illuminance daylight, and 4) daylighting and electric lighting, higher ambient illuminance daylight, and the last group will be kept as a reference group. During each condition, the following will be tested: visual performance via digit symbol substitution test (DSST), visual appearance of light via a semantic differential scale. Background data and alertness via Karolinska Sleepiness Scale (KSS) will also be collected.

On-site measurement of melanopic equivalent daylight illuminance (mEDI), vertical illuminance (Ev), horizontal illuminance (Eh) at 0.80 m above the floor, spectral power distribution (SPD), outdoor lighting conditions, and energy use will be conducted during the tests.

Subjective data will be used to understand how different light distributions might affect the visual performance and visual appearance of light, suggesting whether one solutions should be preferred for visual aspects. For the non-visual aspects, the mEDI will be used as target variable. The recorded data will be used to draw different scenarios where daylighting and electric lighting will be combined in order to reach the target mEDI while minimizing the energy use for lighting.

3. Results

The experimental set-up is currently being finalized and the test subjects will take in the experiment during spring 2023.

One expected result is that the setting with higher ambient illuminance would result in better visual performance and comparatively better perceived quality of lighting. It is hypothesised that this setting would obviously reaching higher mEDI, possibly at no costs in terms of energy use for electric lighting.

A second hypothesis of the study is that daylighting from windows alone can cover most of the required illumination to meet the non-visual requirements. When projected scenarios are considered, it is expected that daylight could cover large part of non-visual requirements through the year.

4. Conclusions

The study will draw conclusions about the effect of directionality of electric lighting and energy use. Two major conclusions are expected. Firstly, that future lighting design should continuing focusing more on vertical surfaces for both visual and non-visual requirements. Second, that it is critical to consider daylighting in any future integrative lighting project.

RESEARCH ON THE EVALUATION METHOD OF SPATIAL BRIGHTNESS FOR CLASSROOM LIGHTING ENVIRONMENTS

Kai, L.[1,2], Min, C.[1], Fan, C. [2], Xiaoyang, H.[2], Nianyu, Z.[2]
[1] CQC Standard (Shanghai) Testing Technology Co.,Ltd., Shanghai, CHINA, [2] Research Institute of Photonics, Dalian Polytechnic University, Dalian, CHINA
liukai@cqc-standard.com.cn

Abstract

1. Motivation, specific objective

With the continuous development and improvement of human factors lighting research, while satisfying the functional lighting of indoor spaces, people are pursuing more breakthroughs and innovations in light quality and light health. The evaluation of the quality of the lighting environment gradually expands from the traditional work surface illuminance to the spatial brightness, so as to improve the observer's visual performance and visual perception. However, through a survey of the current situation, it was found that the conventional lighting environment evaluation system represented by the illuminance of the working surface cannot accurately represent the spatial brightness of the lighting environment. Even in a space with good spatial brightness, the phenomenon of low illuminance on the working surface often occurs. Therefore, this research proposed an evaluation method of spatial brightness for classroom lighting environments.

2. Methods

Combined with the observer's field of view, the evaluation indicators of spatial brightness are proposed: the spatial brightness index B_{SI} and the spatial brightness contrast B_{SC}. Use B_{SI} and B_{SC} to measure the brightness and the chiaroscuro of the lighting environment respectively. And the design method and calculation method of applying it to the classroom lighting environment are given, which is convenient for the application and promotion of the method.

3. Results

1) Conducted on-site research on classroom lighting environment, the factors affecting the size of the evaluation indicators are analyzed, and the design method of the evaluation indicators are given. The result shows that: the size of the light-emitting surface of the luminaire, the direct luminance of the luminaire, the distance between the luminaire and the human eyes, the ratio of the uplight and the reflectivity of each surface will all affect the spatial brightness indicators. The lighting design should be reasonably designed according to the actual situation, so that the teachers and students can feel a bright and comfortable classroom lighting environment;

2) Combined with the actual test and simulation, the calculation methods of the spatial brightness indicators are given. The result shows that: the spatial brightness indicators can be obtained through actual test and simulation, and the consistency between the measured results and the simulation results is high. It can well evaluate the brightness and the chiaroscuro of the lighting environment;

3) Counted and analyzed of the experimental data of the observer's subjective perception under different spatial brightness indicators. the comfort zone of the evaluation indicators are explored, and the limit range of the evaluation indicators are given. The result shows that: to create a lighting environment with good spatial brightness, the B_{SI} should be greater than or equal to 30 cd/m^2, and less than or equal to 200 cd/m^2, and the B_{SC} should be greater than or equal to 0.5;

4. Conclusions

This paper takes the classroom lighting environment as an example to study the evaluation method based on the spatial brightness, which can supplement the current lighting environment evaluation system, and has certain reference value to further improve the current test standards and improve the quality of the lighting environment.

PO64

INFLUENCE OF INDIVIDUAL'S LIGHT ENVIRONMENT EXPERIENCES ON CHOICE OF SEAT AND LIGHTING SUITABLE FOR EACH TASK IN ACTIVITY BASED WORKING

Nomura, A. [1], Iwata, T. [1] Tsushima, S.[1]
[1]Shibaura Institute of Technology, Tokyo, JAPAN
dz19128@shibaura-it.ac.jp

Abstract

1. Introduction

The Activity Based Working (ABW), in which workers can choose workplace depending on objectives and requirements of their tasks, has been recommended in offices. While ABW generally refers to choosing the suitable seating position and type for the task, choosing the suitable lighting for the task and the seat is also important for ABW. There are individual differences in suitable lighting even when the task is the same. One of the reasons for this is the difference in individual's light environment experiences. The purpose of this study is to identify the influence of individual's light environment experiences on choice of seat and lighting suitable for each task in ABW.

2. Methods

In this study, it is considered that workers would select the suitable seat for their tasks and then select the suitable lighting for the seat. It is also considered that there are cases in which workers select lighting directly from the task, regardless of seat selection. In the process of selecting seat and lighting, it is hypothesized that personality and mood would influence seat selection, and that the individual light environment experience would influence lighting selection.

Although ABW can be used for a variety of office activities, this study deals with ABW in a narrow sense, focusing on two types of individual work, thinking tasks (skill tasks) and simple tasks (manual tasks). Therefore, seats suitable for these tasks were adopted: "concentration seats" with a closed field of view and "distraction seats" with an open field of view. As for the lighting, correlated colour temperature (CCT) and illuminate distribution are examined.

Two web-based surveys were conducted in 2022. The first survey was designed to understand individual's light environment experiences, while the second survey was on ABW seat and lighting preferences.

The first web-based survey asked about age, gender, feeling of eye fatigue, vision correction, and visual acuity. The respondents answered the following about light environment experience: tools used for work (computer, tablet, paper, etc.), and working place(living room, café, university, etc.), type of lighting fixtures(celling lighting, pendant lighting, etc.), the colour of light, the illuminate distribution, the shadow at hand, glare, and light environment satisfaction. The colour of light is selected from the following four colours: orange yellow, yellowish white, white, and bluish white. The illuminance distribution was selected from the following five: only the periphery is illuminated, the periphery is brighter than the desk surface, uniform, the desk surface is brighter than the periphery, and only the desk surface is illuminated.

The second web-based survey asks respondents selected photos of seat and lighting suitable for a given task. Photographs were taken for twelve conditions, two seats, two CCT and three conditions of illuminance distribution. The CCT of the task area was set to 2400K and 18000K. It is said that 18000K light increasing arousal level more than 2400K light. Three conditions were prepared for the illuminance distribution in the task area, uniform distribution, the centre is brighter than the surroundings, and only the centre is illuminated. The validity of using these photographs was indicated by a preliminary subjective experiment showing that the correlation between the photo-based evaluation and the evaluation using the actual space

was significant. The respondents ranked the preference of lighting, as well as respondents answered questions regarding their personality using TIPI-J.

Thirty respondents (14 males and 16 females) between the ages of 18-23 years completed both web-based surveys.

3. Results

The results of the first web-based survey show that 67% and 70% of the respondents used white light for a thinking task and a simple task respectively. It was shown that 60% and 57% of the respondents used a uniform illuminance distribution for a thinking task and simple task respectively.

The results of the second web-based survey show that the results of TIPI-J divided respondents into three groups: a group showing personality without distinguishing features, a group showing lower openness, and a group showing higher cooperativeness. The third group choose “distraction seats” with an open field of view for a thinking task, while 70% of the respondents choose “concentration seats” with a closed field of view. The respondents preferred 2400K light to 18000K light, and preferred uniform illuminance distribution to no uniform distribution regardless of the task. There was a tendency to prefer an illuminance distribution in which the illuminance in the centre part was higher for a thinking task rather than for a simple task.

When the relationship between the light environment experience and the lighting preference were examined, the data from the respondents who were dissatisfied with their experiences were excluded, because it is assumed that dissatisfied light environment experiences have a small impact on lighting preferences. Since the lighting preference in the second web-based survey did not include white light, the data from the respondents who used white light in their light environment experience were excluded. The results showed that the light colour of the light environment experience and lighting preference matched 74% for the thinking task and 56% for the simple task, while the illuminance distribution of the light environment experience and the lighting preference matched 46% for a thinking task and 57% for a simple task.

4. Conclusions

The light environment experience survey indicated that most respondents used white light and uniform illuminance distribution for both thinking and simple tasks. There was little diversity in light environment experiences, so that no clear relationship was obtained between light environment experiences and lighting preferences.

PO67

THE EFFECTS OF URBAN MORPHOLOGY ON WINDOW VIEW

Sabet, P.[1], Ciampi, G.[1], Scorpio, M.[1], Sibilio, S.[1]
[1] Dipartimento di Architettura e Disegno Industriale, Università degli Studi della Campania Luigi Vanvitelli, Aversa (CE) 81031, ITALY
parinaz.sabet@unicampania.it

Abstract

1. Motivation, specific objective

Windows have always served multifunctional roles in buildings. The two most significant objectives of windows are daylight and a view of the exterior. In addition, according to the available studies on the significance of view quality, high-quality views are also associated with quantifiable work performance and financial benefits in workplaces. Therefore, it has been observed that early assessment of the view can be beneficial for design decisions made in the initial design stage, such as the orientation of the building, the plan layout, and the facade design, which can increase the quality of the window view. At the same time, urban morphology defined by buildings and their related open spaces, plots or lots, and streets can strongly affect the view quality.

This paper presents the preliminary research results aimed at evaluating the effect of urban configurations, such as building height, surface fluctuation, building complexity, and spatial distance among buildings, which can influence window view.

2. Methods

The research starts with reviewing landscape metrics performed to characterize urban buildings and classify urban morphology. So, representative reference morphologies reflecting typical urban structures and building systems are identified.

Each urban configuration is modelled in the software ClimateStudio upon varying: (i) landscape composition, (ii) architectural cultures, and (iii) climate conditions. The quality of the window view is evaluated using the criteria proposed in EN 17037 and LEED.

Finally, the investigation tries to underline the main relationship between the morphological elements and the view quality.

3. Results

The review underlines that building height, surface fluctuation, and building complexity can be considered to describe the spatial heterogeneity of urban buildings and identify different urban morphology.

Preliminary results show that urban morphology, such as roads dimension or buildings spatial heterogeneity, influences window view quality.

4. Conclusions

This research highlights the need to include more cities of varying morphologies worldwide, as well as to perform subjective assessments to explore relationships between occupants' satisfaction with and numerical characterization of window view.

PO71

IMPACT OF NATURAL LIGHT PENETRATION ON OCCUPANTS IN UNDERGROUND SPACE: AN FIELD QUASI-EXPERIMENT STUDY

Su, H., Liu, X.J., Yang, B.
iLLab, Harbin Institute of Technology, Shenzhen, CHINA
yangbiao@hit.edu.cn

Abstract

1. Motivation, specific objective

As a critical component of indoor environment, natural light is closely associated with human. But the natural light is limited in the underground space, and a large number of workers in the world spend longtime in the space with little natural lighting every day. The space lacking natural light was found to be associated with stress, mood, circadian rhythm disorder, and inhibition of productivity in workspace. Many researchers focused on the advantage of natural light on people. However, most of previous studies were conducted experiments in labs, few field study was founded, especially field quasi-experiment study. In the current study, we aimed to explore the impact of proportion of natural light in the underground space on the occupants.

2. Methods

A quasi-experiment was conducted to compare the impact between light environment with different proportion of natural light on occupants' work performance. The quasi-experimental design is based on differences-in-differences (DID), a nonexperimental technique to estimate the average treatment effect on the treated by comparing the difference across time in the differences between outcome means in the control and treatment groups.

The two experimental points were chosen in one site, one was in the space without natural light in the daytime, the other was in the space with natural light in the daytime. And each point was measured two times in daytime and night respectively. In total, four groups of data were obtained from each site. To eliminate other interference from inherent difference between four sites, the difference of data between two points in each site was indicated the impact of specific proportion of natural light on occupants.

The quasi-experiment was carried out in four underground sites with four proportions of natural light (0%, 7%, 26%, 97%) in Jinan, China. The proportion of natural light was the ratio of the illuminance difference between daytime and night to the illuminance of daytime. There were 12 participants (8 males and 4 females, 18-28 years) were recruited in the quasi-experiment. Each participant was scheduled to undertake the same test for two times at 16:00 and 20:00 respectively in all four sites. In other words, each participant took eight tests and each test took about 7 minutes.

There were three groups of assessment: emotion, work state, and cognitive tasks performance. For emotion and work state, all 11 items (anger, confusion, depression, tension, fatigue, vigor, difficulty, concentration, work efficiency, pressure, and visual evaluation) were collected from subjective questionnaires, including. Assessments of cognitive tasks performance were measured using Letter Cancellation Task (LCT) and Number Calculation Task (NCT). At the beginning of each test, the participants were asked to adapt to the lighting condition for 1 minute. Then the participant was asked to fill the questionnaire and undertake the LCT and NCT whilst the experimenter recorded the number of errors and the actual time spent on the tasks.

3. Results

For subjective emotion score, three items (confusion, depression and vigor) were significantly different between the space with 0% natural light and 97% natural light at the significance level of 0.012 (confusion), 0.024 (depression), and 0.013 (vigor) respectively. The scores of confuse and depression was lower in the space with 97% natural light (confusion: mean = -0.27, depression: mean = -0.15) than 0% natural light (confusion: mean = -0.27, depression: mean = -0.15), while the scores of vigor was higher in the space with 97% natural light (mean = 1.11) than 0% natural light (mean = 0.33). No significant difference was found in the other conditions.

For subjective work state score, two items (difficulty and concentration) were different significantly between the space with 0% natural light and 97% natural light at the significance level of 0.027 (difficulty) and 0.024 (concentration). Both of them were higher in the space with 97% natural light (difficulty: mean = 2.08, concentration: mean = 1.5) than 0% natural light (difficulty: mean = 0.42, concentration: mean = -0.25). The scores of concentration was different significantly between space with 0% natural light and 26% natural light at the significance level of 0.007. It was higher in space with 26% natural light (mean= 1.08) than 0% natural light (mean= -0.42). There was no significant difference between space with 7% natural light and 0% natural light.

For cognitive performance, the significant difference was only between space with 97% natural light and 0% natural light. The task time was lower in space with 97% natural light (mean= -34.67) than 0% natural light (mean= -6.75). No significant difference was found in the other conditions.

4. Conclusions

In general, the results showed that the higher proportion of natural light brought greater benefit to people worked in underground space. In the process of increasing the natural light penetration of underground space, the depression of occupants was relieved, and concentration was improved firstly. Then the confusion of occupants was reduced, and productivity was increased.

The four proportions of natural light at sites distributed unevenly as a result of the proportion which was calculated from measurements. Therefore, we will add other field quasi-experiment sites with diverse proportion of natural light in the future.

The results of the quasi-experiment suggest the benefits from natural light on occupants, which supported the similar results from experimental studies in labs. It will also provide some reference for the design of underground space light environment.

PO75

CHARACTERISTICS OF LIGHT EVALUATION BY ELDERLY PEOPLE UNDER HIGHLY ILLUMINATED ENVIRONMENTS

Umemiya, N.[1], Fukada, S.[1], Minami, T.[1]
[1] Osaka City University, Osaka City, JAPAN
umemiyanor@omu.ac.jp

Abstract

1. Motivation, specific objective

The ratio of people over 65 years old has been increasing in Japan. It reached 29.1% in 2022. Nevertheless, maintaining the labor capabilities of elderly people is necessary because of the declining birthrate. Government reports describe that 45.7% of men 70 years old were employed at some job in 2020. Given such circumstances, it is important to arrange light environments that are appropriate for elderly people.

In 1995, Yokota proposed high illuminance levels for elderly people: 1.5 times more luminous general lighting and 2.0 times more luminous working lighting compared to the industrial standard for ordinary people. Optical deterioration, muscle weakness, and increased scattered light are considered.

This study assesses the subjective responses of elderly people to highly illuminated environments compared to college-age students for attributes related to light environment evaluation such as eyesight, wearing vision correct devices, sensitivity or preference for a light environment, and eye strain. Ordinary illuminated environments are also evaluated.

2. Methods

Experiments were conducted to examine 119 elderly people and 73 student participants. The mean age and standard deviation of the elderly people were 75.5 and 6.5 years. They resided in their homes independently: not in nursing homes. Conditions of participation were age of 65 years old or more with normal eyesight for their age. 55.4% of the elderly people and 67.7% of the students wore glasses or contact lenses.

Illuminance at the center of the desk was set as about 3300 lux for the bright light condition and as about 600 lux for the ordinary condition by controlling the ceiling light. Participants sat and filled out the questionnaire sheets.

After the eyesight of a participant was measured, the participant entered the experimental room, filled out questionnaire sheets with descriptions of physical condition, preferences for the light environment and lifestyle habits. After about ten minutes had elapsed since the participant's entrance, a light environment evaluation sheet was filled out, with queries about the brightness, glare, comfort, preferences, and performance of the light environment. This procedure was repeated three times for each participant. The participant then left the experimental room and entered again after walking in the corridors for about five minutes. First and third experiments were conducted under brighter light conditions; the second was conducted under ordinary conditions.

3. Results

3.1 Eyesight, wearing glasses or contact lenses

Participants were divided into two groups of participants with eyesight over and under the median value of 0.6. The higher eyesight group of elderly people reported a brighter

environment and less glare than the lower eyesight group under brighter light conditions (*p* =5% and less than 0.1%, respectively). The higher eyesight group of students felt more comfortable than the lower eyesight group under the brighter light condition (*p* =5%).

Students with glasses or contact lens felt lower comfort, more glare, and lower preference under brighter light conditions than students without glasses or contact lenses (*p* =1%, under 0.1% and 1% respectively) and reported that it was darker, with less glare, lower comfort, and lower performance under the ordinary light condition than students without glasses or contact lenses (*p* of less than 0.1%, 1%, 5% and 5% respectively).

3.2 Eye fatigue level

Elderly people with more eye fatigue reported more glare, lower comfort, lower preference, and lower performance than those without eye fatigue under the brighter light condition (*p* =5%,1%, 1% and 1% respectively). Elderly people with more eye fatigue reported lower performance than those without eye fatigue under normal conditions (*p* =5%).

3.3 Subjective sensitivity to glare, preference for uniform brightness

Compared to elderly people who did not report sensitivity to glare under bright light conditions, elderly people who declared ‘I am sensitive to glare’ reported more glare (p < 0.01%). Students who declared ‘I am sensitive to glare’ reported more glare and lower preference than students who made no declaration, under bright light conditions (*p* =2% and 5%). Elderly people who declared ‘I am sensitive to glare’ reported a brighter environment and higher performance than elderly people without such a declaration under ordinary conditions (*p* =1% and 5%).

Elderly people who declared ‘I prefer a uniformly bright room’ reported brighter conditions, higher preference, and higher performance than elderly people who made no such declaration under bright light conditions (*p* =5%, 1% and 5%). Students who declare ‘I prefer the uniform bright room’ reported feeling more comfort, higher preference and higher performance than students without such a declaration, under the bright light condition (*p* =2%, <0.01% and 2%). Elderly people who declared ‘I prefer the uniform bright room’ reported more glare than elderly people without such a declaration under normal conditions (*p*=5%).

4. Conclusions

Under highly illuminated conditions and ordinary light conditions, 119 elderly people and 73 students evaluated various aspects of the light environment. The findings from analyses of those evaluations are presented below.

1) Elderly people with better eyesight reported a brighter environment under highly illuminated conditions. Light evaluations did not differ between the brighter light and normal conditions for students.

2) No differences in light environment evaluations were found between responses from participants with and without glasses or contact lenses under either light condition. Students with glasses or contact lenses reported more glare, lower comfort and lower preference under the brighter light condition and reported darker conditions with less glare than those without glasses or contact lenses under ordinary conditions.

3) Elderly people with more eye fatigue reported more glare, lower comfort, lower preference, and lower performance than those without eye fatigue under the bright light condition. Elderly people with more eye fatigue reported lower performance under normal conditions. By contrast, no relation was found between the evaluation and eye fatigue for students.

4) Both elderly people and students who declared ‘I am sensitive to glare’ reported more glare, but the degree of relation was higher for elderly people than for students.

Elderly people who declared ‘I am sensitive to glare’ reported brightness even under the ordinary conditions, but no difference was found according to the sensitivity for students under ordinary conditions.

5) Both elderly people and students who declared ‘I prefer a uniformly bright room’ reported higher preference under the bright light condition, but the tendency was found to be higher for the students.

PO76

OCCUPANTS' SENSITIVITY TO DAYLIGHT SPECTRAL COMPOSITION AND WINDOW VIEWS: RESULTS FROM EXPERIMENTS CONDUCTED IN DENMARK AND BRAZIL

Vasquez, N.G.[1], Fonseca, R.W.[2], Pereira, F.O.[3], Krüger. E.L.[2], Toftum, J.[1]
[1]Technical University of Denmark, DENMARK; [2]Federal University of Technology – Parana, BRAZIL; [3]Federal University of Santa Catarina, BRAZIL
natgir@dtu.dk

Abstract

1. Motivation, specific objective

The spectral composition of the light impacts our physiological responses. Even though the changes might be subtle to the eye, glazing properties affect the visible transmittance, solar transmission, and spectral composition of the natural light. Moreover, windowed rooms also significantly influence people's psychology and well-being, not only because of daylight provision but for the information we can get from the outside. Thus, aside from the visible transmission of the glazing, daylight spectral composition and features of the outside view should be studied together. The integration of those visual parameters have been incorporated recently by international standards and building certifications, highlighting the complex function that windows are expected to attend. However, window design must serve the needs drawn by the latitude and weather, pointing to different solutions according to regional differences.

This paper aims to examine whether occupants, under normal conditions of work in offices, are sensitive to changes in the spectral composition of natural light and view/no view to the outside. Alongside this, we aim to study the effect of regional differences (such as season and daylight availability) on occupants' subjective responses and work performance.

2. Methods

Ninety-six participants volunteered to participate in two experiments conducted in naturally lit rooms and controlled indoor temperature, simulating an office environment. The experiments were conducted in two different locations (Denmark and Southern Brazil) between October and November 2022 (fall and spring seasons, respectively). Thus, half of the participants took part in Experiment 1 (Denmark) and half of them in Experiment 2 (Brazil). In Experiment 1, participants were exposed to two urban views towards a courtyard or a parking lot and three types of window glazing: low iron (T_{vis}= 0.92), tinted (T_{vis}= 0.55), and low emissivity (T_{vis}= 0.82). In Experiment 2, participants were exposed to an urban view or avoided the view to the outside (participants were seated with the window in the back), and three window glazing were examined: neutral coating (T_{vis}= 0.70), silver coating (T_{vis}= 0.38) and reflective champagne coating (T_{vis}= 0.38). Therefore, participants of each experiment were exposed to 6 conditions, with a duration of exposure of 30 minutes. For both experiments, the order of exposition was balanced. During the experimental sessions, participants completed paper-based questionnaires and performance tests. At the same time, we were recording environmental parameters such as rooms equipped with instruments to measure air and globe temperature, air velocity, relative humidity, vertical and horizontal illuminance, correlated color temperature and light spectral composition, and CO2 concentration.

3. Results

Data analysis is ongoing and include descriptive statistics and statistical modeling considering indoor environmental parameters (e.g., horizontal and vertical illuminance, peak of spectral distribution and view out/ no outside view) as predictors and, tests performance and subjective responses (visual sensation, preference, comfort, and acceptability) as outcomes. Additionally, the relationship between participants' responses and geographical location, which translates into climate and daylight availability differences are being examined.

4. Conclusions

From Experiment 1, we expect to understand whether participants performing the paper-based task are sensitive to daylight's spectral distribution changes due to the glazing type and view. Furthermore, we expect to identify whether there is an interaction between the participants' responses, the outside view, and the peak of the spectral distribution reached under each window glazing. Such information might be relevant to further developing standards on building daylighting and views. From Experiment 2, we expect to identify the effect of natural light on occupants since half of the sample was prevented from looking through the window. Moreover, from Experiment 2, it is expected to highlight that although the visible transmittance is the same in some glazing, the spectral composition of light is different- which might be a fundamental property to be informed by the glass producers. Data from both experiments it is expected to provide information about the changes in participants' responses due to regional differences.

PO78

EVALUATION STRUCTURE OF VISUAL ENVIRONMENT CAUSED BY WINDOWS: RELATIONSHIP BETWEEN VIEW AND DAYLIGHTING

Ohki, C.[1], Yoshizawa, N.[2], Matsuda, K.[2], Hori, Y.[3], Matsunaga, S.[4], Oe, Y.[2], Kato, M.[5], Munakata, J.[6]
[1] Obayashi Corporation, Tokyo, JAPAN, [2] Tokyo University of Science, Chiba, JAPAN,
[3] YKK AP Inc., Toyama, JAPAN, [4] YKK Inc., Toyama, JAPAN, [5] Nihon University, Chiba, JAPAN,[6] Chiba University, Chiba, JAPAN
ohki.chikako@obayashi.co.jp

Abstract

1. Motivation

Daylighting is one of the important factors for creating a comfortable indoor environment. Some daylighting metrics ensure daylight sufficiency, and the recommended amounts of daylight available inside rooms have been determined based on the occupants' evaluation of adequate daylighting. However, WELLS (1965) indicated that occupants' estimation of the daylight amount did not correspond with the actual values, especially for those working far from the nearest windows. Moreover, our previous investigation showed that occupants who enjoyed a sufficient view from their desks estimated the daylight amount to be much higher than the actual values. Therefore, we hypothesised that the view quality from windows will be the basis of the evaluation of visual and light environments due to windows, including the psychological sufficiency of daylight, and verified this hypothesis by constructing an evaluation structure using Covariance Structure Analysis.

2. Methods

In this study, we considered two cases regarding the evaluation structures in a visual/light environment due to windows: one for residential spaces and another for workspaces.

1) Residential spaces: A web-based questionnaire survey on the effects of windows in residential spaces was conducted in the autumn of 2018. The number of valid responses was 3634, aged between twenties and seventies (in their 10s–30s:36.8%, 40s:34.3%, 50s–70s:28.9%). Of the total respondents, 61.4% lived in detached houses and the rest lived in apartments. The main questionnaire items concerned the comprehensive evaluation of windows in a living room, light and visual environment in a room, privacy, surrounding environment around the house/apartment, window equipment, physical properties of windows, and the attributes of the respondent. Factor analysis (maximum likelihood method, promax rotation) was performed to extract the latent variables. Using these variables and checking the correlation/partial correlation coefficients among the observed variables, several evaluation structure models were devised and verified with Covariance Structure Analysis.

2) Workspaces: A subjective experiment was conducted on the effects of several windows (horizontal waist windows facing different directions) in three workspaces (10 m in width and 9 m in depth) in an office building during the winter of 2020. Thirteen participants in their early 20s, participated in this experiment. The main questionnaire items concerned the comprehensive satisfaction level of the visual/light environment owing to windows, evaluation of view and daylighting, spatial brightness, and daylight glare. The analysis procedure was the same as that used for the data of the residential spaces mentioned above.

3. Results

1) Residential spaces: Factor analysis showed that three latent variables, View Quality, Lighting Quality including daylight, and Privacy, could be extracted; therefore, we built the basic evaluation structure in which the Comprehensive Evaluation of Windows was placed on

the highest rank, followed by these three latent variables, with subsidiary observed variables under each of them. As a result of the examination of various models, the structure in which View Quality had a causal effect on Lighting Quality showed the highest goodness of fit; that is, the goodness of fit index (GFI) was 0.988 and root mean square error of approximation (RMSEA) was 0.042, which is generally regarded as a high/sufficient goodness of fit for describing how well the model fits a set of observations. The standardised path coefficient from View Quality to Lighting Quality was 0.52, and that from Lighting Quality to the Comprehensive Evaluation of Windows was 0.31. The path coefficient from the View Quality to the Comprehensive Evaluation of Windows was 0.37.

2) Workspaces: Workability, View Quality, Daylighting Quality, and Daylight Glare were extracted from factor analysis as latent variables. As the correlation/partial correlation coefficients between the Comprehensive Satisfaction Level of Visual/Light Environment and Workability were extremely small, we built a basic evaluation structure model with these two variables at the highest rank. Daylight Glare was removed from the model because it worsened the goodness of fit of any models we examined. This was because Daylight Glare was not an issue in these experimental spaces, and only positive evaluation data were collected. As a result of the examination of various models, the structure in which View Quality had a causal effect on Daylighting Quality again showed the highest goodness of fit; that is, GFI was 0.985 and RMSEA was 0.031. The standardised path coefficient from View Quality to Daylighting Quality was 0.49, and that from Daylighting Quality to the Comprehensive Satisfaction Level of Visual/Light Environment owing to Windows was 0.42. The path coefficient from the View Quality to the Comprehensive Satisfaction Level of Visual/Light Environment was 0.36.

4. Conclusions

Both analyses using data from the residential spaces and workspaces yielded the evaluation structure, in which View Quality had a causal effect on Lighting (Daylighting) Quality. This indicates that the view quality from windows will be the basis for the evaluation of visual and light environments due to windows, including the psychological sufficiency of daylight. There remain unexamined issues: 1) This evaluation model does not consider the effect of skylights, which generally introduce daylight into rooms without sufficient view. 2) It is necessary to check the amount of daylight that will be assured by the windows when the view quality meets the demands of the occupants. Note that this evaluation structure only deals with the psychological effects of visual environment on occupants; therefore, if the psychological aspects of daylight sufficiency can be almost satisfied by the easy-to-use view metrics, then we could make use of daylighting metrics for clearer purposes, such as energy saving by introducing daylight into the interior zones, or the assurance of physiological effects on occupants.

PO80

REPRODUCTION OF DAYLIT ENVIRONMENT IN WORKSPACES USING LED LIGHTING VERIFICATION OF THE INFLUENCE OF VIEW FROM A WINDOW

Akuzawa, Y.[1], Xiang, L.[1], Oe, Y.[1], Yoshizawa, N.[1], Nakaso, M.[2], Kaiho, K.[2], Shinohara, N.[3]
[1] Tokyo University of Science, Chiba, JAPAN, [2] Nikken Sekkei, Tokyo, JAPAN, [3] Tokai University, Kanagawa, JAPAN
7122502@ed.tus.ac.jp

Abstract

1. Motivation, specific objective

It is well known that daylighting can improve health and comfort. Considering these benefits, reproducing daylight would be useful for people who cannot get sufficient daylight in workspaces without any windows. Recently, LEDs whose intensities and colours can be easily controlled have been developed and creation of various lighting environments has become easier. However, daylighting is quite different from standard electrical lighting in various aspects. For example, daylighting changes constantly and irregularly in its intensity and colour. Additionally, in the daylit environment, there is usually a view from the side window. Since these multiple features of make reproduction of the daylit environment complicated, there is a need to clarify the necessary elements to get the same positive effects as daylighting. This study deals with ‘view’ and clarifies whether the psychological evaluation such as the impression of the lighting environment, atmosphere, fatigue, and workability (simple tasks), and the state of physiological stress change depending on the presence or absence of the view when reproducing daylighting with LED lighting.

2. Methods

In order to compare daylighting and LED lighting which reproduced the daylit environment, two types of experiments were conducted with the same protocol. First, from August to November 2021, the daylighting experiments were conducted in the experimental workspace (W 2700 mm x D 2700 mm x H 2200 mm), which had a window of 1200 mm x 970 mm on the south wall. The subjects were seated in pairs facing each other and were able to see outside view from the window. During the experiments, the illuminance and the correlated colour temperature (CCT) at the vertical eye level (H 1200 mm) were measured every 15 seconds, and luminance images were taken with CCD cameras every 5 minutes. For comparison with the LED lighting, the experimental data were used in which fluctuation of illuminance and CCT during the experiment were within a set criterion (ratio to each mean value). Second, from May to June2022, the experiments with LED lighting which could reproduce a wide range of light intensities and colours were conducted in the same experimental space as the previous experiments. The window was screened with a translucent diffusion filter to remove the outside view, and the LEDs were installed behind it. Based on the data from the daylighting experiments, three illuminance levels of the lighting conditions of 120 lx, 300 lx and 600 lx in front of the eyes were used and the CCT was set to 5500 K. Each condition was adjusted to approximate the spatial luminance distribution of the condition of daylighting at the same illuminance level.

The experimental procedure was as follows. First, the subjects adapted to darkness for 6 minutes. Next, after adapting to the lighting conditions for 2 minutes, they performed the psychological evaluation and 8 minutes of paper-based tasks such as associative work of words and creating brief poems. They then performed the psychological evaluation and 6 minutes of dark adaptation again. This process was repeated three times in one experiment. The total time of each experiment was approximately 70 minutes. During the experiments, wearable heart rate sensors were used to measure the subjects’ physiological responses. The psychological evaluation was conducted on a total of 55 items regarding lighting environment,

atmosphere, fatigue, and workability. The subjects were 18 students in their twenties with normal colour vision.

3. Results

The psychological evaluation of daylighting and LED lighting were compared at each illuminance level and statistical analysis was conducted using the Wilcoxon rank-sum test ($p<0.05$). At 120 lx, daylighting was perceived as brighter and more uneven in the space than LED lighting. As for the atmosphere, daylighting was evaluated as more open and safer. LED lighting was evaluated as wider and more natural than daylighting at 300lx, and brighter in the space, less stressful, and easier to concentrate at 600lx.

As for the physiological effects, changes in the heart rate (HR) and high-frequency components (HF) of HRV after exposure to lighting conditions were analysed. HR represents the balance of the autonomic nerves, and HF reflects the action of the parasympathetic nerves. The decrease in HR indicates a less stressful state than when it remains unchanged. The Wilcoxon signed-rank test was used for statistical analysis for the HR variability before and after exposure to the lighting condition ($p<0.05$). At 120 lx, HR significantly decreased only in daylighting, indicating that the daylighting was less stressful than LED lighting. At 300 lx, both daylighting and the LED lighting did not change significantly in HR and HF. At 600 lx, HR significantly decreased only in LED lighting, and LED lighting was less stressful than daylighting.

4. Conclusions

At 120 lx, the daylit environment with the view brought psychologically more positive effects, although it caused more unevenness and was physiologically less stressful. At 300 lx, the environment without the view was psychologically better than the daylit environment with the view, but there was little difference in the physiological effects. At 600 lx, the environment without the view was psychologically better, especially in terms of workability, and physiologically less stressful. Although the result at 600 lx was significantly different, the reproduction by LED lighting at that illuminance would not be an issue when working on simple tasks because the absolute values of the evaluation were positive in both environments with and without the view. Therefore, considering the general light intensity when working, it could be feasible to obtain sufficient effects in workspaces by reproducing daylighting with the pseudo window using LED lighting. In the next step, other elements of daylighting also need to be examined to determine whether the same effects as daylighting could be obtained with LED lighting.

PO81

VIEW EVALUATION INDEX USING VISIBLE VOLUME IN OFFICE BUILDINGS

Arano, K.[1], Ohki C[2], Oe, Y.[1], Munakata, J.[3], Kato, M.[4], Yoshizawa, N.[1]
[1] Tokyo University of Science, Chiba, JAPAN, [2] Obayashi Corporation, Tokyo, JAPAN
[3] Chiba University, Chiba, JAPAN, [4] Nihon University, Chiba, JAPAN
kaorij7th@gmail.com

Abstract

1. Motivation, specific objective

Bringing daylight into rooms via windows is critical in promoting the spread of Net Zero Energy Buildings (ZEBs) and achieving the U.N.'s Sustainable Development Goals (SDGs). However, with the increased luminous efficiency of LEDs, which might replace daylight, it has become increasingly difficult to demonstrate the value of windows solely in terms of energy savings. One important function of windows is the acquisition of information about the outside environment, and occupants can refresh themselves or gain a sense of well-being by looking outside. Several findings have been accumulated to clarify the effects of this view. A previous study has shown that view quality consists of three primary variables: view content (the sum of the visual features seen in the window view), view access (the amount of view that an occupant can see from their viewing position), and view clarity (how clearly the content appears in the window view). In LEED and EN17037, the evaluation criteria focus on view content and access. However, there are currently no firm and generally-agreed quantitative indices that can fully explain view quality. This study focuses on a physical quantity called 'visible volume', which contains information encompassing both view content and view access. The purpose of this study is to verify the validity of this index in office buildings by analysing the relationship with the view evaluation obtained through subjective experiments.

2. Methods

The experiments were conducted during the daytime at three rental office buildings with different views in Tokyo for two to three days per building. There were ten participants (university students in their 20s) in the experiments each day. Seven to nine conditions of windows were set up for each building. Five locations at 2.175 m intervals from the windows were used as evaluation points, and the participants were seated at these points in random order facing the windows or the side wall perpendicular to the windows. After that, the participants observed the space by looking around for 20 seconds with their body orientation fixed and evaluated their impressions related to the view such as 'view satisfaction' and 'quality of landscape'. At that time, the luminance distribution and vertical illuminance in front of their eyes were measured using CCD cameras (RICOH, THETA Z1) and data loggers (T&D, TR-74Ui), respectively. Using fisheye images and simulation software (Radiance), the 'solid angle', 'luminance', and 'visible volume' were calculated for each view element (buildings, sky, and ground). The visible volume is the solid angle multiplied by the cube of the distance from the observation position to the objects and is calculated for objects that are visible in the hemisphere with the viewing direction as the zenith. This index encompasses both view access (the solid angle of the object) and view content (the distance to the object). Although the distance to the sky is physically infinite, when calculating the visible volume, the distance to the sky is assumed to be 1 km. The surrounding buildings were treated as those located within a radius of 1 km from the centre of the building where the experiments were conducted. By conducting a single regression analysis with these indices as explanatory variables and the evaluation of the view as the objective variable, the physical quantities that could quantitatively evaluate the view quality were extracted.

3. Results

‘Logarithm of the solid angle of the windows’ and ‘logarithm of the visible volume of the buildings or sky’ had a relatively high correlation with the evaluation of the view ($0.60 \leq R \leq 0.80$) and were likely to explain the view quality. In contrast, ‘luminance of the window or sky’ had a low correlation (R=0.21 and 0.22) and little relationship with the view quality. In addition, since ‘visible volume’ had a much higher correlation than ‘solid angle’ with respect to buildings and the sky, the result was shown that indices that consider distance to each view element may provide a better explanation. However, the large differences in the evaluation of views among conditions, even for the same visible volume, made it clear that it is difficult to determine the view quality using only one variable. To examine an index that takes into account both the solid angle of the window and the distance to each view element, the relationship between the evaluation of the view and the total visible volume, defined as the sum of the visible volume values for each view element (buildings, sky, and ground), was verified. Because the total visible volume shows a higher correlation (R=0.83) with view satisfaction than does either the solid angle of the window only (R=0.63) or the visible volume of each view element only (building only: R=0.76, sky only: 0.80, ground only: 0.69), it is considered appropriate as an evaluation index of the view. These results show the possibility of constructing a predictive model of view quality by considering the distance to the view elements as well as the properties of the window itself such as its apparent size.

4. Conclusions

This study focused on view indices in office buildings and examined the relationship between psychological and physical quantities obtained through subjective experiments. The results show that view quality, such as satisfaction with view and quality of landscape, can be evaluated by total visible volume, which considers the ‘distance to each view element’ in addition to the ‘solid angle of the window’. In the future, we would like to clarify the view indices through examinations in various areas and verify the validity of the evaluation method using the indices in actual offices.

PO89

CAUSAL CONNECTION BETWEEN PSYCHOLOGICAL VIEW AND DAYLIGHTING EVALUATION IN LIVING SPACES

Budoh, Y.[1], Sasaki, S.[1], Oe, Y.[1], Yoshizawa, N.[1], Kishimoto, N.[2], Taniguchi, K.[3]
[1] Tokyo University of Science, Chiba, JAPAN, [2] YKK AP, Tokyo, JAPAN,
[3] The University of Tokyo, Tokyo, JAPAN
bigtheyb@icloud.com

Abstract

1. Motivation, specific objective

In recent years, because of the high efficiency of LED lighting, the window design method which relies solely on metrics for building energy performance by using daylighting have been difficult to be employed in some cases. Therefore, there is a greater demand for useful view metrics as performance evaluation of windows. There are already some view metrics in LEED (Leadership in Energy and Environmental Design) and EN17037: European Daylight Standard, however, the relationship between daylighting and view has not been fully examined. Because both factors are caused by the same windows, there will certainly be some relation between them, and if this relation can be clarified, more efficient guideline for designing windows could be proposed in future. In this study we focus on the psychological effects of view and daylighting in some residential spaces and examined the evaluation structure on the visual environment related to windows, using the data from questionnaire survey which was conducted in Tokyo metropolitan area.

2. Methods

A web-based questionnaire survey was conducted through a market research company to collect the data necessary for the analysis. The main purpose of this questionnaire was to survey the adjustment actions to the environment caused by windows in houses, but evaluation items, which related to visual environment, were extracted and analysed in this study. The number of responses to this questionnaire was 900, in which 866 were valid responses. Respondents were aged 25 to 60, with approximately 1.62% of them in their 20s, 18.9% in their 30s, 41.9% in their 40s, and 37.5% in their 50s and older. Of the total respondents, 62.9% of the respondents lived in detached houses and the rest of them in apartments. In this study, covariance structure analysis was used to organize the relationship between daylighting and view quality, as well as the relationship among occupants' overall satisfaction with the visual environment in living spaces and other evaluation items related to daylighting and view. Covariance structure analysis can quantify the relationship among 'observed variables', which are directly measured variables, and 'latent variables', which lie behind them and cannot be directly observed. It is possible to visually express the relationship among observed and latent variables by using path diagrams.

3. Results

To create a path diagram, we first conducted a factor analysis with ten observed variables, such as 'not being seen from outside', 'outdoor visibility', 'preference of landscape', 'spaciousness', 'satisfaction with view', 'daylight sufficiency', 'daylight control', 'satisfaction with light environment', and 'privacy', and extracted three common factors (latent variables): 'View Quality', 'Daylighting Quality', 'Privacy'. At first, we made a path diagram, in which the causal relationship from 'View Quality' to 'Daylighting Quality' and 'Privacy', and from these three latent variables to 'Overall Satisfaction with the Window' was assumed. 'Overall Satisfaction with the Window' (observed variable) was regarded as the comprehensive evaluation and positioned at the highest in the evaluation structure. The result of the

covariance structure analysis on this model showed that the goodness of fit, GFI (Goodness-of-Fit Index):0.939 and RMSEA (Root Mean Square Error of Approximation):0.100 was not enough to accept this model as a statistically reliable evaluation structure (*usually the model with GFI > 0.95 and RMSEA < 0.1 can be evaluated as acceptable). The latent variable 'Privacy' included the evaluation other than those related to the visual environment of the window, therefore, we excluded this latent variable from the model, and instead included the observed variable 'not being seen from outside' directly to the evaluation structure. Then, we created the second path diagram, in which the causal relationship from 'View Quality' to 'Daylighting Quality' and 'not being seen from outside', and the causality from these two latent variables to 'Overall Satisfaction with the Window' was assumed. As correlation/partial correlation analysis showed that 'not being seen from outside' had no strong relationship with 'Overall Satisfaction', we did not link these two variables directly in this path diagram. The result of the covariance structure analysis on the second model showed that the goodness of fit, GFI:0.969 and RMSEA:0.084 was high enough to accept this model as a reliable evaluation structure. The standardised path coefficient from 'View Quality' to 'Daylighting Quality' was 0.91, and that from 'Daylighting Quality' to 'Overall Satisfaction with the Window' was 0.38. The path coefficient directly from the 'View Quality' to the 'Overall Satisfaction with the Window' was 0.46. As a positive causal relationship was found from 'View Quality' to 'Daylighting Quality', the 'Overall Satisfaction with the Window' can be guaranteed to some extent by ensuring 'View Quality' from the window.

4. Conclusions

In this study, we constructed an evaluation structure for the visual environment provided by windows in residential spaces based on the web-based questionnaire survey conducted in Tokyo metropolitan area in Japan. As a result, it was clarified that 'Daylighting Quality' in living spaces is influenced by 'View Quality' evaluation and leads to the 'Overall Satisfaction with the Window', which indicates that 'View Quality' could be the basis for evaluating the comprehensive visual environment owing to windows. In the future, we would like to examine some quantitative and easy-to-use indexes to evaluate 'View Quality'.

PO92

RESEARCH ON THE INFLUENCE OF COLORED LIGHTING IN LIVING ROOM ON SPACE ATMOSPHERE PERCEPTION AND MOOD

Dai, S.J.[1,2], Li, J.J. [1,2], Li, J.L. [1,2], Hao, L.X.[1,2]
[1] School of Architecture and Urban Planning, Tongji University, Shanghai 200092, CHINA
[2] Key Laboratory of Ecology and Energy Conservation of High Density Habitat, Ministry of Education (Tongji University), Shanghai 200092, CHINA)
haoluoxi@tongji.edu.cn

Abstract

1. Motivation, specific objective

Lighting in living environment has a significantly emotional and physiological influence on residents. More and more colored light sources are used in residential lighting products. The residential interior design also pays more attention to the sense of atmosphere colored lighting creating. However, what kind of colored lighting residents of different genders need in different situations at home. It deserves a more scientific investigation. The present research investigates the effects of color and eye illumination of lighting in living room on space atmosphere perception and mood.

In addition to subjective indicators related to mood, the present study uses wireless electrocardiographic monitoring to obtain mood-related objective physiological indicators such as heart rate and heart rate variability to reflect the real-time emotional state of the occupants. During emotional activity of brian, the activity of the autonomic nervous system brings about a series of changes in the cardiovascular system reflected in the heart rate, the arousal state of the body, etc. Therefore, the data related to heart rate can reflect the functional activity of the autonomic nervous system and the emotional state of the body.

2. Methods

We built a high-fidelity typical living room space in Huizhou City in China with 10 colored lighting scenes. They are red (H: 360, S: 100, L: 100), yellow (H: 60, S: 100, L: 100), blue (H: 200, S: 100, L: 100), green (H: 120, S: 100, L: 100), and white (H: 0, S: 0, L: 100) with two eye vertical illumination levels (200lx and 20lx) respectively.

Twenty-five subjects (9 males and 16 females) experienced 10 lighting scenes in a randomized order. After experiencing each scene for 3 minutes, they filled in a spatial atmosphere perception evaluation questionnaire, which contains 14 pairs of bivariate adjectives highly correlated with spatial lighting perception. They are Natural/ unnatural, Comfortable/ uncomfortable, deadly/vibrant, old/ fashionable, bright/ dark, casual/ formal, and so on. Subjects selected the corresponding adjectives according to the perception of space with colored lighting. Then, electrocardiographic monitoring was performed using a wireless electrocardiograph. After that, subjects completed a Self-emotion Assessment Test. They see 4 positively and 4 negatively emotionally arousing pictures in different colored lighting scenes and evaluated the current emotional state by using the Self-Assessment Manikin (SAM), which is a non-verbal pictorial assessment measuring the pleasure, arousal, and dominance associated with a person's affective reaction to stimuli. The experiment was conducted for a total of 10 minutes in each colored lighting scene. Subjects rested with their eyes closed for 3 minutes between different lighting scenes.

3. Results

In terms of space atmosphere perception, red light was perceived as the faintest ($p<0.05$), the most closed ($p<0.05$), the most unnatural ($p<0.05$), and the warmest light ($p<0.05$). Blue light was perceived as casual ($p<0.05$), bright ($p<0.05$), funky ($p<0.05$), vibrant ($p<0.05$), open ($p<0.05$), cool ($p<0.05$), and bland ($p<0.05$). Yellow light was the dullest ($p<0.05$) as well as

the hardest light ($p<0.05$). White light was the most natural ($p<0.05$), the clearest ($p<0.05$), but the oldest ($p<0.05$) light. Green light was perceived as the softest light ($p<0.05$).

Bright lighting scenes were perceived as clearer ($p<0.001$), more formal ($p<0.001$), more open ($p<0.001$), brighter ($p<0.001$), but also harsher ($p<0.001$). And dark lighting scenes brought a softer feeling, while dim, blurred, random, and closed. For the same lighting scenes, male subjects perceived more discomfort, harshness, and blandness than female subjects.

Self-emotion Assessment Test showed that red, blue and white light were more pleasurable. While yellow, green and white light were more arousing, but not significant. Red light performed with the highest dominance and green with lowest dominance ($p<0.005$). In the same colored lighting scene, arousal scores were higher for males than females ($p<0.001$), while pleasure and dominance ($p<0.005$) were higher for females.

Electrocardiographic monitoring data showed that males had lower mean heart rate ($p<0.05$), and LF (Low Frequency Power), LF/HF ratio ($p<0.05$) than females. High Frequency Power (HF) in bright light was significantly lower than dark ($p<0.05$), indicating higher parasympathetic activity and lower alertness in dark lighting scenes. The heart rate of subjects in red and yellow light environment was higher than in blue and green light. Although the results of color-based electrocardiographic monitoring data data analysis did not reflect significant differences.

4. Conclusions

Different colors and brightness of lighting design in living environment will bring different feelings to the residents. When designing lighting for a living room, differences in home behaviors or genders of residents could be taken into account. Based on the analysis of the above experimental data, we propose the following recommendations for colored lighting design of living room:

1. The most high-frequency behaviors in living room includes meeting guests, leisure, sports, etc. When meeting guests, we need clear, natural as well as formal light. Bright white light is recommended. For casual and soft leisure space, dim red or yellow light is recommended. Energetic, fun and not harsh blue light is recommended when exercising. Bright or dim lighting, it depends on what exercise you are doing.

2. There are also significant differences in the perception of space between women and men. Female occupants are more sensitive to color than male. It is recommended to use less saturated color lighting when lighting for women. Males are more sensitive to the perception of brightness than female. So soft light is recommended.

3. The alertness of people in bright environment is higher than in dark. If you need to work or play games at home, you can increase the eye illumination to enhance alertness. But high light level should be avoided when you eager to be relaxed.

PO93

LIGHTING CONDITIONS IN DUTCH HOME OFFICE SPACES – A FIRST INVENTORY

de Kok, V.C.A.J. [1], Christoffersen, J.[2], van Duijnhoven, J.[1]
[1] Eindhoven University of Technology, Eindhoven, The NETHERLANDS
[2] VELUX, Hørsholm, DENMARK
v.c.a.j.d.kok@tue.nl

Abstract

1. Motivation

The effects of light on the visual system are well-understood and represented in national and international lighting standards, such as the EN 17037 (2018) or the EN 12464-1 (2021). Office lighting is often designed complying to these standards, hence, the lighting conditions in these spaces are generally of adequate quality. However, research in the past years has shown that lighting is not only important for the visual system, but that it can also initiate effects beyond vision. No official standards for lighting regarding the non-visual system exist yet. Elaborating on this, there is no lighting standard for offices that considers visual and non-visual effects simultaneously. Since the COVID-19 pandemic, in 2021 around 30% of the Dutch working population worked from home more often than prior-pandemic, and around 70% have the intention to stay working from home at least one day a week post-pandemic. No standards regarding lighting for the home work space exist (yet). Thus, it is unknown whether the lighting conditions in home office spaces are adequately designed for office tasks. This research therefore aims to understand the current lighting situation in home office spaces in The Netherlands, with the ultimate goal to aid home workers in designing the lighting environment in such a way as to benefit both the visual and the non-visual system.

2. Method

To gain an understanding of the lighting conditions in Dutch home office spaces, an online questionnaire was developed in LimeSurvey. Interviews with relevant experts and pilot tests were conducted as part of the development process. The questionnaire was accessible from November 21st 2022 until February 17th 2023. The questionnaire consisted of 46 questions divided over seven sections: 1) informed consent 2) demographics, 3) home office characteristics, 4) behaviors and tasks executed in the home office, 5) subjective evaluation of home office characteristics, 6) open question on desired changes to the home office visual environment and 7) pictures of the home office workplace and window view. The survey was distributed through the researcher’s personal LinkedIn network, the VELUX LinkedIn network and in person by handing out QR codes that linked to the survey. Additionally, the Dutch lighting association (NSVV) spread the survey through their website, a mailing list consisting of people who downloaded a document with general lighting design tips for the home office, and their monthly newsletter. Lastly, acquaintances and relatives were asked to spread the questionnaire in their respective networks. Inclusion criteria were: 1) participants had to live and work in The Netherlands, 2) participants had to work from home at least one day a week and 3) participants had to be aged between 18 and 67 years old. Participants could choose whether they answered the questionnaire in English or in Dutch, to increase the questionnaire’s accessibility for non-Dutch speakers living and working in The Netherlands. The data were processed in R version 4.2.1.

3. Results

In total, 112 complete responses were collected. The respondents indicated to use multiple spaces in their house as their home office, with most participants indicating to have a room dedicated to the home office (63.4%), followed by using the living room (19.6%). Other places that were used as home office were the bedroom and the kitchen. The orientation of the window(s) in the home office space was most often indicated to be South or West (both 25.9%), followed by East (23.2%) and North (21.4%). 3.6% of the respondents reported not to know the orientation of their window(s). Most participants indicated to have the window either

on their left or right side (combined 67.9%). Additionally, 27.7% faced the window directly. The remaining participants either had the window behind them, or above their head. 84% of the respondents sat at a distance of 0 to 2 meters from the window. Most participants indicated to be satisfied with the daylighting in their home office space (88.4%). However, still 46.4% of the respondents indicated to use additional electric lighting when daylight was present. The main reason given for this was that especially during winter or cloudy days, too little daylight is available in the space. 86.6% of the participants indicted to rarely or never experience glare from electric light sources in their home office. In contrast, almost 41% of the participants indicated at least sometimes being bothered by glare from daylight. Thematic analysis of the open questions regarding which changes participants desired to make to their home office visual environment, showed that approximately 37% would not desire any changes. However, other participants mentioned, amongst others, that they would like to have better lighting for online meetings to make their faces better visible, they would like to have more daylight in their space, and they would like to have less direct sunlight entering the space, or be better able to control direct sunlight, to avoid glare or overheating of the room.

4. Conclusions

Working from home is a phenomenon that has been spreading for a while and is likely to continue doing so. Even though this study showed that more than 63% of the participants have a room in their house dedicated to the home office, a house is built for housing needs, and as such, it is not necessarily apt to provide comfortable working spaces. The results showed that there are many differences between individual home working spaces, and that the needs with regards to lighting differ per individual office worker. Whereas standards are available to guide lighting design for the visual system in traditional offices, for the home office environment these standards do not exist (yet). Moreover, no official standards considering non-visual effects of light exist. As such, the challenge is to develop an integrative home office lighting recommendation for laymen to help them make informed decisions regarding (day)lighting design in their home office space, in order to improve their visual environment whilst at the same time improving their luminous exposure to harvest the non-visual benefits of lighting.

PO98

VALIDATION OF THE EFFECTIVENESS OF USING MINDFULNESS CONTENT WITH LED PANEL LIGHT FOR HOME

Fujiwara, Y.[1], Ikebuchi, M.[1] and Tanaka, T.[1]
[1] Panasonic Corporation, Kadoma, JAPAN
fujiwara.yuri@jp.panasonic.com

Abstract

1. Motivation, specific objective

Mindfulness is a way of focusing our mind on the present moment and observing ourselves by meditation. Recognized as effective in improving mental and physical health, productivity, and interpersonal relationships, it has been adopted by many companies for their training programs. In recent years, research has been conducted to validate the effectiveness of mindfulness, not only in clinical practice, but also as part of neuroscientific approaches. Since our modern society is overwhelmed with information that requires cognitive processing, it is important to practice mindfulness in our daily lives. However, it is difficult for beginners to practice mindfulness. Even if they do, they will not be motivated to continue unless they can see the benefits. Therefore, we propose LED panel light that supports mindfulness by dynamically changing the brightness. By the feature, people can practice mindfulness easily in their homes and experience the benefits.

2. Methods

Lighting apparatus used in this study was a LED panel light with a speaker. The apparatus has a feature with fluctuates the brightness evenly or unevenly. A combination of four different types of dynamic control was used as a mindfulness content and throughout the experience, the speaker played music and voice guidance as a support. The first phase was a relaxation phase in which subjects take deep breaths following the light-dark rhythm of low correlated colour temperature (CCT) light. The next phase was a concentrated meditation phase to focus attention on oneself by concentrating on periodic changes of brightness. This was followed by an observed meditation phase in which unevenly changes brightness helps the subjects to become aware of changes around oneself. Finally, there was a recovery phase in which the lighting gradually changes to higher CCT to facilitate a smooth return to daily life.

26 subjects (women in their 30s to 40s) participated in this study. The lighting apparatus was installed at the living room of the subject’s home. This experiment was carried out in a dark living room with only the experimental apparatus turned on.

Experiments were conducted under the following three conditions: constant low CCT and low light intensity (Control), “fluctuating light only”, and “fluctuating light with sound (BGM and guidance)”. Subjects performed seven minutes of mindfulness once a day for two consecutive weeks under each condition. A one-week reset period was used when switching from one condition to another.

Effects of mindfulness were evaluated using visual analogue scale (VAS). The following items were taken through the meditation experience, “Mood, Calmness, Relax, Refresh, Anxiety, Meditation support, Mindfulness achievement” for each mindfulness. Additionally, the items below were taken before going sleep “Motivation, Efficiency, Concentration, and Confidence to homemaking or work”. This study also investigated the effects of continuous use with “Five Facet Mindfulness Questionnaire (FFMQ)”.

3. Results

From the two-week experiment on each condition, the following significant effects were observed in comparison with the Control condition. The evaluation before and after each meditation showed a significant improvement in Mood, Calmness, Relax, and Refresh for the "fluctuating light with sound" condition . Additionally, the evaluation after each meditation showed a significant improvement in Meditation support and Mindfulness achievement in both the "fluctuating light only" and "light with sound" conditions. However, the evaluation taken before going to bed for each meditation and the evaluation of continuous use showed no significant effects.

4. Conclusions

From this study we presume that fluctuating light supports meditation and brings sense of mindfulness achievement more effectively than meditating in a constant low CCT and low light intensity environment. It is presumed that adding sound to fluctuating light further enhances the mood and promotes relaxing and refreshing feelings.

No significant effects were found in the evaluation of continuous use, which may be because the technical psychological/psychiatric questions in the FFMQ made it difficult for non-experts to evaluate. However, in the subjective evaluation for each meditation, Mood, Calmness, Relax and Refresh scores before mindfulness were higher throughout the period when subjects meditated in the "fluctuating light with sound" condition for consecutive days, indicating that continuous use of this condition is effective.

The results suggest that the use of LED panel with fluctuating light features can help people achieve a mindfulness practice at home, and therefore, has the potential to improve the quality of life of the user.

PO104

CAN AMBER LED LIGHTING AFFECT VISUAL ABILITY AND CAUSE EYESTRAIN?

Hemphälä, H.[1], Lindén,J.[1], Skjöld, A.[2]
[1] Lund University, Design Sciences, Lund, SWEDEN, [2] Skjöld/Skjöld & Grönvall, Malmö, SWEDEN
hillevi.hemphala@design.lth.se

Abstract

1. Motivation, specific objective

In a pilot intervention study with integrative LED lighting at a psychiatric ward at a hospital in the south of Sweden, a problem arose among the staff at night. Some of the night shift workers complained about severe headache and a lot of eyestrain, problems focusing and other visual problems when working nights in amber lighting. After discussions with some of the workers it appeared that the individuals with problems had incorrect power in their spectacles, or other visual problems, that affected their visual acuity. This, in combination with the amber lighting, is believed to be the cause of the problems.

To be able to read the pupil needs to constrict to focus and see clearly on a near distance, when orange light (589 nm) is used the pupil constricts less than with blue enriched light (4000K). This could cause a decrease of the visual ability in amber light. This might be affected even more if the individual has wrong power in their spectacles and therefore lower visual acuity. The standard visual acuity is usually 1.0 for right and left eye, separately.

2. Methods

The intervention lighting at night changed from fluorescent lighting at 2700 K to LED amber at 1750 K. Both situations had about 50lx in the corridors of the ward.

All the night personnel (n=8) got a thorough visual examination and six of them received personally customized spectacles with correct power. Their visual acuity was measured before and after new power at the visual examinations (1.0 is standard). Four of them answered a Visual Ergonomics Risk Assessment questionnaire online (VERAM) with questions regarding eyestrain, headache, and visual ability, before and after the new spectacles. In VERAM, the total amount of eyestrain consists of the sum of the frequency (0=never to 3=almost every day) of nine different symptoms (smarting, itching, gritty feeling, pain, photophobia, redness, teariness, dryness, eye fatigue, with a maximum of 36). The workers rated their visual ability from very bad to very good (0-4) and presence of headache from never to almost every day (0-4).

3. Results

The visual acuity for right and left eye (R/L) increased for the four workers after the new spectacles; worker 1 from 0.8/0.8 to 1.2/1.2, worker 2 from 0.17/0.17 to 1.0-/1.0- (cataract surgery and new spectacles), worker 3 from 0.8/1.0- to 1.0/1.0, and worker 4 from 1.2-/1.0+ to 1.2-/1.2-.

The total amount of eyestrain decreased for all four workers (10 to 6, 27 to 19, 6 to 0, and 4 to 2) and the visual ability increased or stayed the same after the new spectacles. Only two of the participants had headache and for one of them it reduced and for the other there were no difference.

One individual had an early cataract after a trauma, and after surgery and new spectacles problems decreased. The participants experienced it better working in the amber lighting after new spectacles.

4. Conclusions

Despite the low number of participants, the study shows a potential problem working in amber lighting with wrong power in spectacles. The visual ability can be affected by the amber lighting, and the amount of eyestrain can also be affected by the individual's visual acuity and if they have correct power in their spectacles. The amber light can reduce the ability to focus and read and therefore it might be necessary to recommend visual examinations and correct spectacles when working in amber lighting. Presbyopic individuals might have more visual challenges in amber lighting than younger individuals and therefore it might be necessary to have warm white task light for reading or detailed work. More studies are required to gather more information regarding the effect of amber on visual ability.

PO105

THE PERCEPTION OF LIGHT COLOUR IS RELATIVE – A PILOT STUDY DESCRIBING PERCEIVED LIGHT COLOUR

Hiller, C.[1], Wendin, K.[2,3], Enger J.[4]
[1] RISE Research Institutes of Sweden, Borås, SWEDEN, [2] Kristianstad University, Kristianstad, SWEDEN, [3] University of Copenhagen, Frederiksberg, DENMARK, [4] University of Arts, Crafts and Design, Stockholm, SWEDEN
carolina.hiller@ri.se

Abstract

1. Motivation, specific objective

Perceived light qualities of consumer lighting products are generally insufficiently described, reflecting that perception-based qualities are not considered to the same extent as physical measures when creating light environments. Thus, there is a risk for less appealing environments. For example, the perception of light colour – which is not exactly connected to the physically measured colour temperature – where experience shows that the well-established concepts of warm, neutral and cool light colour are often too general to be completely useful in describing perceived light colour.

It is well known that two stimuli next to each other, such as two colours, interact and influence our experience, which can be referred to as the simultaneous contrast effect. Intentional or unintentional differences between two light sources side by side may in this way impact the visual perception of the room, especially regarding perceived light colour.

To develop descriptions of light colour, and mainly to investigate how to describe small differences in perception, new concepts are introduced and evaluated by analytical sensory analysis in a pilot study combining paired comparison tests and descriptive sensory analysis. The paired comparison test identifies whether there is a difference or not between the products and the descriptive analysis is particularly suitable for describing people's objective perceptions, leaving out personal preferences that are not relevant in general descriptions. The later method has previously been applied to lighting products, while the combined approach is new, and of interest to explore.

Hence, the specific objective of the study is to explore how perceived light colour of two white light sources, which is simultaneously compared, can be described using a combination of sensory methods.

2. Methods

Analytical sensory methods, in the form of paired comparison tests in combination with descriptive analysis, were used to explore and describe perceived differences in light colour between pairs of lighting products. Concepts to describe the light colour were introduced to the trained panel, namely warm, reddish, bluish, yellowish and greenish light colour, which were somewhat known to the panellists; and magentaish and cyanish light colour, which were completely new. These concepts were assessed on unipolar line-scales from 0 to 100. The assessments were carried out in three test booths, each supplemented with two white boxes with round openings through which indirect light was visible. The assessments were performed in triplicate and in a randomized order.

The experimental design comprised common consumer products of white LED lighting in the following pairs (data according to product specification):

Pair 1: similar lighting products of correlated colour temperature 4000 K and luminous flux 270 lm

Pair 2: cool products of 4000 K, and 250 lm and 400 lm, respectively

Pair 3: warm products of 2700 K, and 250 lm and 400 lm, respectively

In addition, the correlated colour temperature was physically measured, verifying the properties of the lighting products. The panellists were also asked to give their feedback on how they experienced the combined sensory methods.

The data from the assessments was analysed using Student's t-test, where the significant level was set to $p < .05$. The differences between the lighting sources within each pair, for each light colour-related concept, were compared.

3. Results

The results from the assessments are presented for each pair of light sources.

Pair 1: There were significant differences between the light sources in the perception of warm, as well as cyanish light colour. In general, although not always statistically significant, one light source was perceived to be more cyanish, bluish, and greenish, and the other light source as more warm, reddish, and yellowish. This split between the light sources is in line with the traditional concepts of cool and warm colours. These differences were confirmed by the physically measured colour temperatures.

Pair 2: Magentaish light colour was perceived significantly different between the light sources in this pair. The split between the two products was that one was to a greater degree perceived as more magentaish, reddish, and bluish, while the other was perceived as more greenish, yellowish, and cyanish (not all significant).

Pair 3: This pair demonstrated that there were significant differences for the perceived bluish light colour, although the degree of bluishness was at a lower level than for the other two, cooler, pairs. The light sources split into higher bluish, reddish, and magentaish for one of the light sources, and into warm, yellowish, and greenish for the other. The light source with lower luminous flux was perceived as more bluish, while the one with higher luminous flux was perceived as more yellowish (not significant). This is also in parallel to pair 2.

The panel was generally positive about the new concepts. However, it felt like some colour hues were missing, such as orangish. There were mixed experiences as to whether the pairwise comparisons were easier or more difficult than individual tests where only one light set-up is assessed at a time.

4. Conclusions

The perception of light colour was shown to be relative, demonstrated by cool light sources were perceived as warm/yellowish/reddish in relation to other cool light sources. The significance of the relative experience was also revealed by differences between two similar products are perceptually picked up on when they are placed next to each other. These interactions between two stimuli were well captured by the combined sensory methods with simultaneous light sources.

The very newest introduced concepts, cyanish and magentaish light colour, were found to be useful in describing the perceived differences for two of the assessed pairs, which shows that more concepts than warm, neutral and cool are needed for a richer description of the light colour.

PO109

NEUROPHYSIOLOGY-BASED EVALUATION METHOD IN LIGHTING ENVIRONMENT FOR BRIGHTNESS PERCEPTION OF SIMPLE TARGETS

Inoue, S.[1] Shida, H.[1] Yoshizawa, N.[1]
1 Tokyo University of Science, Chiba, JAPAN
yoshizawa@rs.tus.ac.jp

Abstract

1. Motivation, specific objective

Brightness is one of the important foundations for planning lighting environments. Recently, neurophysiology-based models have received attention as a method to evaluate visual qualities, such as glare and visibility, and there is a possibility to also apply these models to the brightness perception. Based on previous studies of classical fill-in models, we introduce a new model for predicting brightness perception and verify the validity of this algorithm by comparing the predicted values with the subjective evaluation in a laboratory.

2. Methods

In classical fill-in theory, brightness perception can be explained based on feature extraction (e.g. luminance and contrast) and the edge detection of objects in the environment. In our algorithm, the luminance distribution in the visual field, captured from the viewpoint by CCD sensors, is used as input data, and the flow of early visual information processing from the retina to the primary visual cortex (V1) is built up in the algorithm. In this study, optical processes from the pupil to the retina were not taken into consideration.

The outline of the algorithm is as follows.

1) Retina: First, the input data is calculated to local luminance (weighted average luminance in the patch) based on the size of the receptive field of the neuron. Next, using a double Gaussian filter that mimics microsaccades and ocular drift, the half-saturated retinal constant is computed from the local and global luminance (average of the total local luminance on the target). Moreover, taking the influence of the peripheral luminance distribution into account, the local luminance is calculated by a normalization formula using the local luminance and semi-saturated retinal constant. Finally, luminance- and contrast-driven information is calculated using difference of Gaussians (DoG) filters, which mimic the antagonistic centre-surround receptive fields in the early neural processing, at which time contrast-driven information is separated separately by ON and OFF; this separate processing flow is performed until feedback from V1.

2) Lateral geniculate nucleus (LGN): After luminance- and contrast-driven information is relayed from the retina to the LGN, contrast gain control mechanism comes into the operation, then the next stage information of luminance- and contrast-driven are calculated by the normalization formulae using the excitatory and suppressive responses.

3) Primary visual cortex (V1): The cellular responses of simple and complex cell receptor regions associated with edge detection are calculated by the normalized ON and OFF contrast-driven using Gabor filters and energy models. Then, under ON and OFF flows, simple cell responses are normalized with complex cellular responses, and edge information is calculated by integrating ON and OFF calculation responses. The filters and models are based on previous work on edge detection.

4) Feedback from V1: The edge information and normalized ON and OFF contrast-driven information are nonlinearly converted into fill-in information. The feedback mechanism then comes into the operation, and the brightness perception is calculated by integrated response normalized with calculated luminance-driven and fill-in information of feedback.

To verify the validity of this algorithm for applying it to the actual lighting environment, we conducted a subjective experiment using a target with clear or blurred boundary. The target was displayed on a display. We created circular targets with sharp boundaries and ones with

smooth gradation boundaries based on circle and Gaussian functions. These targets have seven levels of central luminance (10, 30, 60, 125, 250, 500, 1000, 1000 cd/ m^2), seven levels of luminance contrast (the value of the central luminance relative to the peripheral luminance: 100, 10, 2, 1, 0.5, 0.1, 0.01), and three levels of viewing angles (1, 10, and 30 degrees). We set the screen maximum luminance to 1000 (cd/m^2) and the γ value to match the display so that the luminance gradation of each target does not change. We darkened the room and covered the display stand and the position of the viewing angle of more than 60 degrees on the screen with black construction paper to prevent light reflection. The subjects evaluated the brightness of the evaluation target on a seven-point scale: 1: not bright at all, 2: almost not bright, 3: somehow bright, 4: can't say either, 5: fairly bright, 6: quite bright, 7: very bright. Luminance distribution was measured for every condition using CANON EOS 5D SR+ Canon EF 20mm F/2.8 from the viewpoint of the subjects.

3. Results

Simple linear regression analyses were applied between the subjects' evaluations (objective variable) and the calculated values of brightness perception using this algorithm (explanatory variable), and a high coefficient of determination of 0.834 was obtained. When the results were separated by the luminance contrast, the coefficient of determination was 0.854 under increment conditions where the central luminance was higher than the peripheral luminance, and the coefficient of determination was 0.530 under the opposite decrement condition. As a result, the algorithm can estimate the brightness perception of an object in the experimental space with high accuracy under direct contrast conditions using blurred images; however, this was not the case with high accuracy under the condition that the central luminance was lower than the peripheral luminance.

4. Conclusions

We created an algorithm that predicts brightness perception along a neurophysiological flow based on classical fill-in models, and its validity was verified through comparison with subjective evaluations. The results of the evaluation experiments confirmed the usefulness of the re-examined brightness perception algorithm for the evaluation of brightness and darkness.

However, there were some inadequacies in terms of the effects of peripheral luminance and edges, such as variations in the results for the decrement condition. Further analysis and validation in a real space with a variety of viewing environments is desirable in the future.

PO115

A STUDY ON RELAXATION AND REFRESHMENT DURING SELF-SEAT BREAKS IN OFFICES

Kato, Y.[1], Yu, H.[1], Akita, T.[1], Hirate K.[1], and Sano, N.[1]
[1]Tokyo Denki University, Tokyo, JAPAN
22fma12@ms.dendai.ac.jp

Abstract

1. Introduction

In recent years, moderate breaks have been recommended to improve intellectual productivity and maintain health, and research on environments that enhance the effects of rest has been ongoing. In Japan, 50.1% of companies with 29 or fewer employees do not have break rooms, and 46.5% of office workers are forced to take breaks in their own seats to refresh themselves. In addition to that, the Ministry of Land, Infrastructure, Transport, and Tourism classifies office behaviors into five categories, categorizing breaks into relaxation and refreshment, but there are few examples of studies that separate these two categories. The purpose of this study is to identify appropriate visual environment elements for relaxation and refreshment during office breaks.

2. Experiment

2.1 Outline

Three factors were used in this study: illuminance, height of partitions, and presence of plants. The partitions were selected because the environmental factors required for relaxation and refreshment differ in terms of the sense of openness depending on how the space is used, and because greening rest rooms are effective in improving subjective evaluations of the plants. Plants were selected because they are effective in improving subjective evaluation of the space. The relationship between these three factors and relaxation/refreshment will be investigated through impression evaluation using the rating scale method.

This study was conducted using a head-mounted display (HMD), and the space was created by Twinmotion (Epic Games) and presented in VR. The space was assumed to be an office, with the dimensions of W:1200mm x D:1000mm x H:3000mm. The entrance to the space is on the south side, five windows are on the west side, and three windows are on the north side. 65 blinds (W:2000mm x D:30mm) were installed in each window with 30-degree rotation to block light from the outside. The office layout consisted of three blocks of nine opposing desks. In addition to the partitions and plants used in the experiment, a computer, stationery, and documents were placed on the desks. These were all built into Twinmotion. In addition, 30 ceiling-mounted, straight-tube LED lamp base lights (paneled type) were evenly distributed. As experimental settings, three patterns of illuminance (200lx, 500lx, 750lx), three patterns of partition height (0mm, 200mm, 500mm), and the presence of plants (with and without plants) were used. 19 subjects in their 20s (M: 21.5, SD: 0.5) participated in the subject experiment, and a 7-point scale was used to evaluate the psychometric quantities. The subjects were asked to evaluate their impressions of the psychometric parameters using a 7-point rating scale. The subjects were asked to evaluate their impressions of the psychometric quantities using a 7-point rating scale method.

Since the participants were wearing HMDs, the evaluation was made verbally. In addition, because VR was used, we measured the physiological index, the flicker value, to confirm whether or not eye strain was present in the experimental results. The experimental procedure consisted of first measuring the flicker value and then closing the eyes for 30 seconds to allow the eyes to acclimate. Next, the participants were asked to view the VR space and evaluate their impressions. This was repeated 18 times. After the 18th repetition, the flicker value was measured.

2.2 Analysis and Results

A three-way ANOVA was performed on the results obtained from the experiment. The results showed that there were some main effects from the height of the partition and the presence of plants, but not from the illuminance. This may be due to the fact that the illuminance was adjusted to the desk surface in the experimental space, resulting in a dazzling effect, and the brightness was not perceived appropriately.

A Turkey-Kramer HSD test was conducted on the items for which main effects were obtained. The results showed significant differences in the relationship between the height of the partition with and without plants for "Relax" and "Refresh," both of which were rated higher when plants were present. There was no significant difference for "Relax" when plants were present. There was a significant difference between 0mm and 200mm and 500mm in the non-plant condition, and the higher the height, the higher the evaluation. There was no significant difference in "Refresh" when plants were present. When there were no plants, there was a significant difference between 0 mm and 500 mm, with 500 mm receiving higher ratings. The above results indicate that the height of the partition has no effect when there are plants in the room. On the other hand, when there were no plants, "Relax" was rated higher when the partition height was 500 mm. For "Refresh," the higher the height of the partition, the higher the rating, indicating that higher partitions are required.

The results of the "Overall Satisfaction" analysis also showed that there was a significant difference between the two types of partitions, with and without plants. 200mm and 500mm partitions showed a significant difference, with 200mm partitions receiving a higher rating. Since there was no significant difference between "relax" and "refresh" with plants, it is thought that factors other than rest influenced the overall satisfaction rating. A comparison of flicker values for eye strain before and after the experiment showed a significant difference, indicating a tendency toward eye strain.

PO116

INFLUENCE OF SPATIAL AVERAGE LUMINANCE RANGE AND EVALUATION TECHNIQUE ON PERCEIVED SPATIAL BRIGHTNESS

Kato, M.[1]
[1] Nihon University, Narashino, JAPAN
kato.mika@nihon-u.ac.jp

Abstract

1. Motivation, specific objective

A committee of the Architectural Institute of Japan (AIJ) has established a working group to develop a standard for spatial brightness.

In order to establish a standard for spatial brightness, it is necessary to understand the level of spatial brightness required for each application, in addition to identifying physical quantities that correlate with spatial brightness.

There have been many studies on the former, and many of them have shown that spatial brightness can be predicted with good accuracy by taking into account the effect of uneven luminance based on the average luminance of the spatial area to be evaluated. However, since the detection of uneven luminance depends on the image resolution of the measurement system, the WG proposes the use of arithmetic mean luminance, which can be obtained relatively stably with any researcher's system.

For the latter, the WG has been conducting evaluation experiments in various lighting environments in order to ascertain the appropriate spatial brightness for different uses. However, even for the same application, there are differences in the average luminance evaluated as "just the right brightness of space.

There are several possible factors. One is the possibility that, as indicated in the previous report, the choice of the interior reflectance of the space may have caused a change in the space brightness that matches the atmosphere, even for the same use. There is also a possibility that different lighting techniques may have caused differences in the degree of luminance irregularity, which in turn may have affected the perception of space brightness differently. Another possibility that has been pointed out in recent years is the effect of range bias.

In this study, after confirming that no change in brightness perception occurred, we conducted an experiment to determine whether range bias affected the spatial brightness requirement.

2. Methods

The size of the space prepared for the experiment is W:5830mm x D:3400mm x H:2700mm. The space use is assumed to be an office. Subjects observed this space and evaluated the adequacy of the space brightness. The experiment was divided into two cases in which subjects were asked to observe the space at four different illuminance levels: 125, 250, 500, and 1000 lx at 70 cm height, which corresponds to the height of a typical desk, and at 250, 500, 1000, and 2000 lx. In addition, each was conducted on a different day.

In addition, to confirm that no change in perceived space brightness occurred, an adjustment box illuminated with uniform light was provided and allowed to adjust to be the same as the perceived space brightness. At that time, we prepared two types of adjustment methods for the adjustment box: slider and scrolling. The maximum adjustable brightness was set at two levels, 1000 cd/m^2 and 4000 cd/m^2. The slider allows subjects to visually grasp the maximum and minimum values that can be output, while the scrolling does not.

The subjects were 19 students in their 20s, 8 were male and 11 were female.

3. Results

The results of the evaluation of the adequacy of spatial brightness showed that the highest percentage of respondents rated 500 lx for 125-1000 lx and 1000 lx for 250-2000 lx as "just right".

In the experiments on spatial brightness perception, the sliders tended to show a relatively good match between the evaluation space and the brightness of the adjustment box.

The slider rated 1000lx and especially 2000lx darker at 1000 cd/m^2 compared to the maximum adjustable value of the adjustment box at 4000 cd/m^2 when the slider was 250-2000lx. At the wheel, no differences due to the dimming range were observed.

4. Conclusions

The experiment revealed the following two things.

1. Although the "slider" can be used to accurately adjust the range of brightness change, a low upper limit value produces an error on the suppression side of the adjustment value in areas of high luminance. Based on the results of this experiment, an error occurred at twice the spatial average luminance, and no error occurred at four times the spatial average luminance.
2. The "just right space brightness" rating would change if the maximum average latitude and minimum average luminance of the presented space differed.

This is expected to have a similar effect in spaces experienced on a daily basis, regardless of the experiment. If one experiences only bright environments, the brightness requirements of the space will be higher, and vice versa. While variety is desirable in terms of design variation, it will also be important for lighting designers not to induce excessive energy consumption. It may be necessary to avoid setting experimental conditions beyond the realistic range of spatial luminance for evaluation. From various perspectives, it is important to control the experimental conditions.

PO119

A NEW WAY OF COLOUR MIXING FOR DAYLIGHT-QUALITY WHITE LED

Lee, T. X., Chuang, K. C.
Graduate Institute of Color and Illumination Technology, National Taiwan University of Science and Technology, Taipei, TAIWAN
txlee@mail.ntust.edu.tw

Abstract

Most modern White LEDs have a CCT between 2,700 and 6,500K. However, to encompass the CCT range of natural daylight, the light source must have a CCT between 1,800 and 10,000K. In this report, we proposed a new way using only three White LED light sources mixed to match the wide CCT range of daylight. In addition, high colour rendering (Ra>95) and low chromatic difference (|Duv|< 0.004) settings are also the standards that daylight-quality light sources should have. Here we evaluated both the visual and non-visual effects of the light source. The results indicated that the proposed White light source outperformed other general White LEDs regarding colour rendering, colour fidelity index, colour saturation index, and spectral similarity index. The fact that the daylight efficacy ratios of the proposed light source were lower than those of the other light sources also indicated that the proposed light source had a weak effect on melatonin. Therefore, the proposed light source can achieve a wide range of CCTs and dynamic white lighting by blending only three LED light sources, which is quite suitable for human-centric lighting.

Keywords: White LED, Daylight, Colour Mixing, Smart Lighting

1. Motivation

Inadequate compatibility of a light source’s brightness and spectral composition may have adverse health effects in the form of decreased attention span, depressed mood, visual fatigue, and vision loss (Wei, 2017). Studies have indicated that the light source's colour temperature affects the physiology of humans, including their heart rate (Ayash, 2015), blood pressure, and brain activity (Abbas, 2006). In addition, light sources with certain colour temperatures positively influence behavioral performance, such as alertness (Viola, 2008), working speed, productivity, and concentration (Mills, 2006). Therefore, factors other than low cost and high light output must be considered in the design of new generations of LEDs (Liu, 2017). Because the vast majority of people feel most comfortable when exposed to natural sunlight, numerous multispectral LED light sources have been designed to provide adequate quasi-natural illumination.

2. Method

We first determined the chromaticity coordinates of 1,800 and 10,000K on a blackbody radiation curve. We then calculated the linear equations of the tangents of 1,800 and 10,000K on the curve. The results indicated that the two tangents met at (0.4027, 0.4324), corresponding to a colour temperature of 3,836K. To obtain the optimal spectrum for the three colour points, we use a combination of various blue LEDs and phosphors. We then used the simulated annealing method proposed to determine the optimal spectrum. The optimized three light source spectra are mixed in different ratios, by sampling CCTs at an interval of 100 K under conditions of Ra>95 and |Duv|<0.004, we identified White LEDs that is fairly close to daylight-quality with variable wide CCTs.

3. Result

We compared the proposed tri-LED White light with common LED White lights on the market. Regarding colour rendering, the Ra values of the proposed tri-LED White light were consistently the highest across the entire daylight colour temperature range, thus indicating that the proposed tri-LED light source outperformed the other light sources. Regarding R9, the tri-LED White light also outperformed the other light sources. Notably, the R9 values of RGB and RGBW light sources are in the negative range, indicating that they are unsuitable for healthy lighting. Regarding chromatic difference, the |Duv| values of the proposed tri-LED White light remained within the range of 0.004, indicating that the white light produced by the proposed tri-LED White light complied with lighting regulations and lacked a yellow-greenish or pink-purplish hue. The daylight efficacy ratio (DER) is an index introduced by the CIE S026 standard. It is the ratio of perceived light (by human eyes) to standard daylight, which can be used to quantify the ability of a light source to inhibit melatonin production. Regarding the DER, the values of the proposed tri-LED White light fell between those of RGB and RGBCW, indicating that the proposed tri-LED White light is unlikely to disrupt the circadian rhythm or cause sleep disorders by excessively inhibiting the production of melatonin. Regarding colour saturation, the optimal value of Rg is 100; values greater than or less than 100 indicate excessive or insufficient colour saturation, respectively. Compared with the other light sources, the proposed tri-LED White light maintained a relatively constant value of 100, indicating its superiority to other light sources. In terms of colour fidelity, an Rf value of 100 indicates that the light source has the same colour fidelity as that of the reference light source, whereas a value of 0 indicates the exact opposite. This study's proposed tri-LED White light outperformed other light sources regarding Rf. Luminous efficiency is denoted by Eff. The CW+WW light source had a higher Eff than those of the other light sources, but this was expected because its Rf was 80. Although the proposed tri-LED White light had a lower Eff compared with the other light sources, its efficiency was within the normal range of LEDs. Lastly, SSI is commonly used in the film and television industry. Its purpose is to ensure that the scenes shot in studios do not contain spectral errors. A value of 100 indicates that the light source performs identically to the reference light source. A value of <80 indicates that the scenes may have chromatic differences and require postproduction computer colour correction. Our proposed tri-LED White light outperformed the other light sources regarding the SSI, demonstrating a value greater than 80, indicating its suitability for the film and television industry.

4. Conclusion

In conclusion, the light source proposed in this study, which can achieve the full range of colour temperatures of natural daylight with only three LED light sources, can be used in smart and healthy lighting to develop white light sources that provide visual comfort without disrupting the circadian rhythm of the users.

PO121

THE COMPREHENSIVE STUDY OF INTEGRATIVE LIGHTING ON THE PERFORMANCE, ALERTNESS, MOOD AND EYESTRAIN OF SCHOOL CHILDREN

Li, J.[1,2], Li, J.[1,2], Dai, S.[1,2], Hao, L.[1,2]
[1] School of Architecture and Urban Planning, Tongji University, Shanghai 200092, CHINA, [2] Key Laboratory of Ecology and Energy Conservation of High Density Habitat, Ministry of Education (Tongji University), Shanghai 200092, CHINA
2010221@tongji.edu.cn

Abstract

1. Motivation, specific objective

Lighting is an essential factor in creating an optimal learning environment for children. Integrative lighting takes visual processes, including working performance of reading and writing, visual display terminal (VDT) and eyestrain, and non-image forming processes, including alertness, mood and sleep, into comprehensive consideration, which was influenced by illuminance, correlated color temperature (CCT), and timing of light. Studies have explored the acute impact of CCT and illuminance of indoor lighting on visual task performance or daytime alertness, however, there wasn’t a consistent and comprehensive study on the optimal lighting environment for children.

2. Methods

The study investigated the effects of different illuminance levels (300 lx vs. 1200 lx) and CCT levels (2800 K vs. 5000 K) on memory, reaction speed, accuracy, subjective alertness and sustained attention, mood, and eyestrain in highly simulated children's study lab. There were 19 healthy school-age children (13 females, 6-12 years) participated in the laboratory study, all of them taking eye examinations and PSQI (Pittsburgh sleep quality index), SAS (self-rating anxiety scale) and SDS (self-rating depression scale) test before the experiment. The experiment was conducted in a highly simulated children's bedroom lab of 4.2 m by 2.6 m, with a set of matte-finished white children's desks (1.2 m length by 0.8 m width by 0.75 m height) and chairs. The experiment was two variables multiply by two levels (illuminance:300lx and 1200lx; CCT:2800K and 5000K) cross-over design, and all the participants have to take four experiments on two different days during it daytime (10:00-15:00), and the interval between two different CCT experiment scenes was one week.

3. Results

Under the condition of reading and writing work, the performance and alertness were enhanced through interaction effects on illuminance and CCT. Given that the spectral energy density of the non-image forming effect was enhanced under high CCT and high illuminance, children had the strongest alertness in 5000K and 1200lx light levels ($p < 0.05$). Under the condition of VDT work, increasing CCT improved performance, which is more effective compared to varying illuminance, for high illuminance causes glare and light veil on the screen. CCT has a greater impact on eyestrain, and low CCT and high illuminance cause the most serious eyestrain($p < 0.05$), for the mismatch between CCT and illuminance brought psychological and physiological imbalance. CCT has a greater impact on spatial perception, and spatial perception is more positive under high illuminance($p < 0.05$).

4. Conclusions

The optimal lighting strategies were different according to different tasks. CCT has a greater impact on VDT performance than illuminance, and illuminance has a greater impact on spatial perception than CCT. The interaction of CCT and illuminance affects alertness, reading and writing performance and eyestrain. The influence of task types under different lighting conditions and interaction effects on CCT and illuminance were discussed.

PO123

LIGHTING ENVIRONMENT DURING BREAKS WHEN WORKING FROM HOME

Mochizuki, E.[1], Tanaka, S.[1], Sato, Y.[1]
[1] Chiba Institute of Technology, Chiba, JAPAN
etsuko.mochizuki@p.chibakoudai.jp

Abstract

1. Motivation, specific objective

The number of the population who are engaged in work from home has increased dramatically due to the widespread of COVID-19. In those cases, they use PC screens for most of their work. In addition, they have shorter breaks while working from home than while working in office. Even when they take breaks, they continuously look at their PC screens, such as by Internet browsing. It is concerned that their visual fatigue might not be reduced by breaks.

The purpose of this study is to investigate the lighting environment during breaks when working from home that can contribute for reducing visual fatigue of the workers even under the condition of continuously looking at PC screens.

2. Methods

Two identical experimental chambers with the same size, 2700 mm in wide, 2000 mm in depth and 2500 mm in height, were prepared for the experiment. Two desks of 740 mm-high with 600 mm- high partitions attached to both ends of the desks were placed in each chamber. Two pairs of ceiling luminaire (SAD423X, 49 W) were equipped on the ceiling in each chamber to illuminate each desk. The desktop illuminance was set 500 lx at 5000K constantly during the task. In addition, four dimmable spotlights (SXS3028W, 13.6 W) were installed in one side chamber to provide variable lighting during breaks around the subjects' desks. In the other side chamber, one ceiling luminaire with projector (popIn Aladdin 2 Plus, 190 W) was set at the centre of the ceiling to project an animated cartoon onto the front wall. The interior surface of the chamber was finished with monochromatic wall paper/carpet, the reflectance of 83% for the ceiling and for the wall, 92% for the partition and 14% for the floor.

Six different conditions as following were examined for the lighting environment during breaks.

A) Constant desktop illuminance of 500 lx at 5000K

B) Constant desktop illuminance of 500 lx with variable CCT (5000K-4000K-3500K-4000K-4500K)

C) Stepping down the desktop illuminance in 100 lx from maximum 500 lx to minimum 100 lx at 5000K

D) Constant desktop illuminance of 100 lx at 5000K with blinking spotlights at regular intervals on the partitions

E) Constant desktop illuminance of 100 lx at 5000K with blinking spotlights at regular intervals on the front wall

F) Constant desktop illuminance of 100 lx at 5000K with projection on the front wall

Eight university students (4 female and 4 male, 22.4 years old in average) participated in the experiment as the subjects. Two subjects at a time stayed in each chamber and performed VDT task using laptop computer (HP Probook 650G5), whose luminance was set at about 100 cd/m^2 in white, twice for 60 minutes with a 10 minutes' break in between.

The subjects were asked to perform three kinds of task for 60 minutes in total -two-digit four arithmetic task, inverted character search task and text typing task each for 20 minutes. After the 60 minutes' task, the subjects took break for 10 minutes while watching an animation

cartoon with sound on PC screen except for condition F). In condition F), the subjects took a break watching an animation projected on the front wall.

Before and after the task, the subjects' visual fatigue was measured by three methods- critical fusion frequency of flicker (CFF) and accommodation response time (ART) as objective test and questionnaire for evaluation of subjective symptoms of fatigue as subjective test. The questionnaires were consisted of all 25 questions concerning the physical and visual fatigue. In addition, the subjects were asked to evaluate the lighting environment of the experimental chamber with each condition as a work space or rest space. Each subject participated in the experiment once a day for approximately 150 minutes and experienced all conditions over 6 days.

3. Results

Visual fatigue due to the task was analysed by the change rate of CFF and that of ART before/after the break in the median of the all 8 subjects. The higher value of CFF means the lower visual fatigue and the lower the value of ART means the lower visual fatigue, i.e. the positive value for CFF change rate and the negative value for ART change rate indicate the reduction of visual fatigue.

It was identified that the change rate of CFF after the break became higher than that before the break except for the condition A), which was the constant condition throughout the experiment. On the other hand, the conditions C), D), E) and F) showed positive values of the change rate of CFF after the break. This indicates that lowering desktop illuminance during breaks may be effective in reducing visual fatigue.

It was identified that the change rate of ART after the break became lower than that before the break only for the condition D) in which the partitions were illuminated by blinking spotlights. The conditions A) and F) showed positive values for ART change rate after the break. However, the results of ANOVA showed no significant difference in the change rate of CFF nor that of ART.

The evaluation of subjective symptoms of fatigue also confirmed that the increase in the total amount of complaints of dullness and that of blurriness due to the task after the break for the conditions D) and E) were smaller than those for the other conditions. However, for the condition B), in which CCT was varied during the break, the total amount of complaints for anxiety and discomfort were significantly higher than those for the other conditions.

4. Conclusions

When the lighting environment was kept constant both during work and during break, it was identified that visual fatigue increased with subsequent task, even if he/she took a break in between. It was identified that visual fatigue could be reduced by lowering illuminance and by providing variable lighting in the peripheral vision field during breaks. Further effective lighting environment during breaks will be investigated that can reduce visual fatigue while maintaining visual comfort, even under the condition of continuous viewing PC screen.

PO128

SPACIOUSNESS EVALUATION DEVIATION CAUSED BY BRIGHTNESS DIFFERENCES BETWEEN REFERENCE AND COMPARATIVE CONDITIONS IN THE MAGNITUDE ESTIMATION METHOD

Nishihara, S.[1], Miyake, H.[2], Horiuchi, Y.[1], Yamaguchi, H.[3], Yoshizawa, N.[1]
[1]Tokyo University of Science, Chiba, JAPAN, [2]Arup, Tokyo, JAPAN, [3]National Institute for Land and Infrastructure Management, Tsukuba, JAPAN
7122565@ed.tus.ac.jp

Abstract

1. Motivation, specific objective

Spaciousness is an important psychological factor that affects the comfort and wealth of occupants. A quantitative evaluation of spaciousness will aid in the effective design of space and lighting. One of the most powerful methods of quantitative study on this topic is with subjective experiments using the magnitude estimation method (hereinafter called 'ME method'). In this method, two conditions, a reference condition and a comparative condition, are prepared. The perceived spaciousness of the reference condition is set as 100, and participants are asked to provide the perceived spaciousness of the comparative condition compared to the reference condition as a positive number. This experimental method faces a problem in which the participants' evaluations cannot be stable when the volume ratio of these conditions was too large. Previous studies have revealed that participants can provide stable evaluations when the volume ratio is between 0.25 and 4 times. Since it has been clarified that volume and brightness both have a significant effect on spaciousness, we needed to examine not only the volume ratio, but also the brightness ratio as well. Participants' evaluations are expected to vary widely when the brightness of the two spaces being compared differs significantly. In this study, we prepared two real spaces and two Virtual Reality (VR) spaces. In each space, we changed only the brightness and asked the participants to evaluate spaciousness using the ME method. Through this experiment, we verified the brightness condition that allowed the subjects to perform stable evaluations.

2. Methods

We prepared four simple experimental spaces without furniture or obstacles. Two of them were real spaces: W6580 x D9730 x H2700mm (large) and W2900 x D4500 x H2700mm (small). The other two spaces were developed with VR. These spaces have been used in previous studies, and they were close in volume to the prepared real space. Their volumes were W7200 x D7200 x H3000mm (large) and W3600 x D3600 x H3000mm (small). In the real space, the vertical illuminance in front of the eyes was set to be one of eight levels from 7.8lx to 1000lx in the geometric sequence with a common ratio of 2. In the VR spaces, the eight levels were from 3.9lx to 420lx in the same way, considering that the maximum output luminance of the head mounted display used, Oculus Quest, was 100cd/m^2. In each of the four spaces, we changed the vertical illuminance in front of the eyes. Participants were asked to evaluate perceived spaciousness using the ME method, with Scheffe's method of paired comparisons (Ura's Paired Comparison) as a reference. In each space, the experiment was conducted under 56 conditions in a round-robin manner. There were a total of 224 conditions. The participants were 14 students in their 20s.

3. Results

The vertical illuminance ratio of the two spaces and participants' logarithmic evaluation values of spaciousness had a strong positive correlation. In other words, the brighter the comparative condition was compared to the reference condition, the more participants feel spaciousness. However, we found a tendency for the standard deviation of the evaluation values to increase under certain conditions. The average of the evaluated values was unreliable under such conditions. When the illuminance ratio of the comparative condition to the reference condition was greater than 1, the standard deviation of participants' logarithmic evaluation value was

approximately 0.15. However, when the illuminance ratio was less than 1, the smaller the illuminance ratio was, the larger the standard deviation was. There were conditions in which the standard deviation was greater than 0.2, which meant that the subjective evaluation varied widely. This trend was similar in both the real and the VR spaces. Conditions with vertical illuminances of 3.9 lx, 7.8 lx, and 15.6 lx were considered mesopic vision. The conditions thus changed from photopic to the mesopic vision. As the participants observed the comparative conditions for only 20s, they were unable to be dark adapted, which may have resulted in differences in the perception of spaciousness under such conditions.

4. Conclusions

In the subjective experiment for spaciousness evaluation using the ME method, some conditions were found in which the subjective evaluation varied widely. There was a tendency for the standard deviation of the subjective evaluation to be large when the comparative condition was darker than the reference condition. The darker the comparative condition relative to the reference condition was, the larger the standard deviation was. Especially in comparisons requiring dark adaptation, where the reference condition was photopic vision and the comparative condition was mesopic vision, this tendency was remarkable. To ensure the stability of subjective experiments, it is necessary to limit the range of the brightness of the conditions just as with the range of the volume. In this experiment, the real space was compared to the real space. The same experiment was conducted in VR spaces. We will conduct the experiments between the real and VR spaces in a future study.

PO129

PREFERRED LIGHTING FOR UKIYO-E, JAPANESE WOODBLOCK PRINT PAINTING

Okuda, S.[1], Taguchi, S.[2], Okajima, K[3], Melgosa, M[4].
[1] Doshisha Women's College of Liberal Arts, Kyoto, JAPAN, [2] Tokyo University of the Arts, Tokyo, JAPAN, [3] Yokohama National University, Yokohama, JAPAN, [4] Granada University, Granada, SPAIN
sokuda@dwc.doshisha.ac.jp

Abstract

1. Introduction

The appearance of the cultural properties depends on the surface color, the material and the lighting condition. Previous research on cultural properties in the field of materials science has greatly contributed to establish guidelines and regulations for exhibitions, preservation and restoration in museums. However, usually these rules do not consider the influence of many lighting options on the visual appearance of cultural properties in museums Therefore, this study aims to clear the preferred lighting conditions for the appearance of the cultural properties. In the present study, we focused on Ukiyo-e, Japanese woodblock print paintings.

2. Methods

Ukiyo-e is one of the paintings established in the Edo period (1603-1868). Generally, it is a multi-colored woodblock print painting, and was very popular among ordinary people. As visual targets, we prepared two kinds of Ukiyo-e, drawn by Toyohara Kunichika who is famous as an Ukiyo-e artist. Ukiyo-e (A) is "Mitate hashi zukushi Nihonbashi", Parody of Collection of Bridges / Nihon-bashi Bridge (1873). An actor of Kabuki, Kawarazaki Sansho, wearing kimono in indigo and white was drawn on the red background, and the bridge is inserted into the picture. Another Ukiyo-e (B) is "Edo meisho awase no uchi Osho Jiro No.7", Famous Views of Edo / Osho Jiro (1867). An actor of Kabuki, Ichimura Kakitsu, wearing a kimono in blue-green and dark blue was drawn on the black background, and the scenery with a bridge is inserted into the picture.

In this study, we investigated the appearance of above pictures under 12 lighting conditions, nine kinds of LED illuminants (B1, B2, B3, B4, B5, BH1, RGB1, LED-V1 and LED-V2) and three conventional illuminants (standard illuminant A, D50 and D65) referred to CIE015-2018, which differs in spectral power distribution. We set that the vertical illuminance on the picture to one of three conditions, 50[lx], 200[lx] and 500[lx].

First, we measured the spectral data of the surface of two kinds of Ukiyo-e using a 2D spectroradiometer [UA-5000, Topcon Co. Ltd.]. Next, we generated the simulated digital image of each Ukiyo-e under 12 kinds of illuminants using the spectral data of pictures, illuminants and the calibration data of an LC-display [CG248-4K, EIZO] which was used in the evaluation. Theoretically, there should be no difference between evaluations of the digital image and the real object. In total, we generated 72 images of the Ukiyo-e, and each image was presented on the display in the evaluations space.

20 Japanese participants with normal colour vision observed each Ukiyo-e, and evaluated the appearance of the picture with 10 pairs of adjectives, "dull - vivid", "heavy - light", "muddy – clear", "old – new", "cold – warm", "inactive – active", "static – dynamic", "traditional – modern", "cheap – high-grade", "uncomfortable – comfortable" and "ugly – beautiful", with a 7 steps scale. Also, they evaluated "preference of lighting" with a numerical scale from 1 (not prefer) to 10 (absolutely prefer). They had knowledge of arts, being familiar with paintings.

3. Results

According to the results, the appearance of Ukiyo-e (A) was relatively dull under the LED illuminants in 50 lx. Also, it was relatively vivid when CCT of the illuminant was from 4000 to 6600 K; illuminant D50, illuminant D65, B3, B4, B5 and LED-V2. The appearance of Ukiyo-e

(B) was more vivid as the CCT and the illuminance were higher. Both of Ukiyo-e look dull under low CCT illuminants.

Ukiyo-e (A) looked more modern as the CCT was higher. Similarly, Ukyo-e (B) was more traditional as the CCT was lower. The “traditional – modern” evaluation was not affected by the colors in Ukiyo-e, and the illuminance on both Ukiyo-e did not affect the evaluation so much under most lighting conditions.

Ukiyo-e (A) was ugly under all illuminants in 50 lx, whereas it was relatively beautiful under the lighting conditions of D50 and B2 in 200 lx. Ukiyo-e (B) was relatively beautiful under D50, B3, B4 and V2.

4. Conclusion

The preferred appearance of Ukiyo-e is affected by the lighting conditions as well as the colors of paintings. We found that low CCT illuminants were not appropriate for good appearance of Ukiyo-e.

PO132

SHORTCOMINGS IN DETERMINING THE LENI INDICATOR ACCORDING TO THE EN 15193 STANDARD

Pekolj, M.[1], Bizjak, G.[1]
[1] University of Ljubljana, Faculty of electrical engineering, Ljubljana, SLOVENIA
Matej.Pekolj@fe.uni-lj.si

Abstract

1. Motivation, specific objective

A large part of the (predicted) energy consumption in residential and non-residential buildings is accounted for by planned or implemented lighting systems. One of the indicators of energy efficiency of the lighting system is the LENI indicator, which, as presented in the EN 15193 standard, can be determined using three different methods. When determining the indicator on real examples, we encountered several shortcomings that are not considered in the determination itself. We have seen that we have to make many simplifications and approximations to certain values in the calculations.

With our research, we wanted to verify the applicability and accuracy of methods for determining the LENI indicator according to the EN 15193 standard on a real example.

2. Methods

The standard presents three different methods for determining the energy efficiency of lighting (called method 1, method 2 and method 3). The most accurate and the only one with data obtained through measurements is method 3, the other two are computational. We compared all three methods on a real example of a commercial building, for which we had all the necessary input data, so that we could determine the LENI indicator using all three methods from the standard.

3. Results

In general, when determining LENI, we noticed that we could not take into account the quality of light and the effects of luminaires and light sources on room heating.

In addition, in the standard it is not possible to find the correct procedure for more accurate determination the daylight availability for façade openings taking into account the thickness of the wall, which also has an impact on the size of the daylight area, in addition to all the factors described in the standard.

During the calculations, we also encountered the problem of how to determine the effect of day lit area on certain lighting subsystems, which are quite far from that area.

Since the standard suggests the use of certain values from the given tables, we used them in the calculations, even though they sometimes seem illogical. We also found that in a building where the largest part of the area is one large room, the lighting of this room has the greatest influence on the LENI value. However, most of the computation time is spent on small auxiliary spaces, which do not have a large impact on the LENI value. In certain cases, smaller rooms could probably be neglected.

Another shortcoming of the standard is that outdoor luminaires are not considered as part of the lighting system for which the LENI is calculated. This also complicates the determination of LENI using method 3, because if an additional energy meter is installed for lighting, in many cases it will measure the electrical energy consumed for indoor and outdoor lighting together.

4. Conclusions

The values of the LENI indicator determined by all three methods for a given commercial building differed significantly due to the shortcomings in the determination methods described above. In the calculations, we mostly used the suggested values from the standard to better compare the results of the methods. It turned out that in examples of lighting systems in buildings, where all the data of the lighting system and the purpose of individual rooms and their occupancy in the building are precisely known, it makes more sense to consider the values determined by ourselves.

PO136

REFLECTED GLARE ON MUSEUM EXHIBITS WITH DISPLAY CASES AN EXAMINATION OF A GLARE PREDICTION METHOD BASED ON LUMINANCE DISTRIBUTION

Sagawa, M.[1], Maeda, A.[1], Mizokami, Y.[2] Takashima, M.[3], Oe, Y.[1], Yoshizawa, N.[1]
[1] Tokyo university of Science, Chiba, JAPAN, [2] Chiba University, Chiba, JAPAN, [3] The National Museum of Western Art, Tokyo, JAPAN
7122539@ed.tus.ac.jp

Abstract

1. Motivation, specific objective

Reflected glare on the surface of exhibits in museums often interferes with viewers' appreciation of paintings. Methods to suppress the reflected glare by devising the positions of luminaires and paintings have been suggested via guidelines. However, in many cases, the reflected glare is caused by a light source for other exhibits or paintings displayed on the opposite wall. Such reflected glare is sometimes difficult to be solved geometrically, and suppression methods have not been clarified. The ultimate purpose of this study is to clarify the mechanism of reflected glare by examining the factors that have not been focused on in the past and to establish a method of suppressing reflected glare that is not restricted by the display case or the type of painting. Our previous study, under conditions without display cases, found that the degree of reflected glare could be roughly estimated from three physical quantities: luminance contrast, reflectance, and glossiness of the painting surface. In this study, based on the results of an experiment on reflected glare using an acrylic display case, differences in the degree of glare for those viewing exhibits were evaluated in comparison to the condition without the display case. In addition, this study examined whether the degree of reflected glare could be predicted from the same three physical quantities regardless of whether a display case is used.

2. Methods

The experiment was conducted in a room with dimensions of 5000 mm (depth) x 2900 mm (width) x 2400 mm (height), assuming the size of an actual gallery in the museum. All surfaces in this space were painted white (N9.5). The participants were 11 university students (six men and five women) in their 20s with normal colour vision. Three types of luminaires were employed: (1) ambient light (LED, Ra:92, CCT:3000K) to illuminate the entire space, (2) spotlight A (LED, Ra:97, CCT:3000K) to illuminate the painting surfaces, and (3) spotlight B (LED, Ra:95, CCT:3000K) to create a reflection of the light source on the paintings. Spotlight A was equipped with a trimming cutter to illuminate only the surface of the replica paints (oil painting, painted with one colour, 410mm (width) x 318mm (height)). The lighting conditions were two levels of illuminance on the floor surface (15 lx, 100 lx), three levels of illuminance on the painting by spotlight B (10 lx, 20 lx, 40 lx), and two levels of illuminance by all the luminaires on the painting (100 lx, 200 lx). The painting conditions were three levels of Munsell values (N1.7, N5.9, N9.4) and two levels of varnish application (no varnish, two layers of varnish) on the painting surface, and five of them were excerpted. The research with the display case included 60 experimental conditions. For comparison, one lighting condition was selected for each painting, and five conditions were set up without the display case. The participant first adapted to the room for 10 minutes after entering the space (the horizontal illuminance in front of the participants was 200 lx). The experimenter set the conditions, and the participant evaluated the painting after 30 seconds of adaptation; then, this process was repeated. The order of presentation of the experimental conditions was randomised for each participant. The evaluation items included questions on reflected glare (eight items) and one question on the overall brightness of the painting excluding the reflected glare.

3. Results

First, a one-way analysis of variance was conducted to clarify the differences in the participants' evaluations depending on the presence or absence of the display case under the same lighting and painting conditions ($p < 0.05$). This study only covers the evaluation of dazzling light caused by reflected glare. The condition with the display case was rated as more dazzling in all compared conditions. To analyse the physical quantities, the luminance ratio was calculated as the mean luminance of high-luminance areas directly illuminated by spotlight B divided by the mean luminance of the other area on the painting. This was based on a condition of a strong light source reflection (the floor surface: 10 lx, the painting surface: 100 lx, the replica paint: N1.7, two layers of varnish). The relationship between the luminance ratio and participant evaluation was confirmed by including the results of a previous study conducted without the display case. This analysis constructed a logarithmic trend line with a high coefficient of determination ($y=1.1\ln(x)+0.91$, $R^2=0.75$). This suggests that the luminance ratio can be used to predict the degree of reflected glare on the painting surface to some extent, regardless of the presence or absence of a display case. However, when examined using the prediction equation with the three explanatory variables calculated in the previous study, the regression equation did not fit ($R^2=0.37$). This result may be because the characteristics of the spread of high-luminance areas on the painting surface differ depending on the painting conditions and display case. Therefore, it is necessary to reconsider the luminance areas to be targeted when calculating the luminance ratio.

4. Conclusions

The degree of reflected glare increased in the display case under all conditions. In addition, the luminance ratio can be used to roughly predict the degree of reflected glare, regardless of whether there is a display case. If the conditions under which reflected glare occurs can be clarified, it is possible to take measures through the planning of lighting in museums when geometric factors alone cannot solve the problem. The characteristics of the high-luminance area on the painting surface owing to the display case and painting conditions will continue to be investigated, and the method for calculating the luminance ratio will continue to be assessed.

PO140

LIGHTING EDUCATION: ANALYSIS OF THE INTERNATIONAL PANORAMA THROUGH A SYSTEMATIC LITERATURE REVIEW

Sousa, J. A. B.[1], Amorim, C. N. D.[1]
[1] University of Brasília, Brasília, BRAZIL
j.andrade.conforto@gmail.com

Abstract

1. Motivation, specific objective

Faced with scientific advances related to light and lighting - ranging from aspects that encompass impacts on human health to technological innovations in components - it is increasingly important to consider the role of teaching lighting offered to professionals in the area, especially those who work or will work in areas related to the built environment. This article aims to understand the general panorama of teaching lighting in the built environment, in order to identify, categorize and analyze the main themes addressed in selected scientific articles.

2. Methods

The method used was the systematic literature review. The Scopus and Web of Science databases were used to search for articles published in journals and event annals, in addition to direct searches in journals focused on the lighting theme (Lighting Research & Technology and Leukos). The searches were carried out in English, using the following descriptors: (1) lighting/light and education; (2) lighting/light and teaching/teaching; (3) lighting/light and curriculum; and (4) daylighting/daylight and education. In all, 40 documents were selected for the research, 39 of which were scientific articles and a report issued by the CIE - Commission Internationale de L'éclairage - in 1992, entitled "Lighting Education".

3. Results

The results allowed the identification of the main aspects discussed around the teaching of lighting in the world context, including educational practices, contents of course programs and evaluations of the quality of teaching. It was possible to identify problems and challenges related to the theme, such as the difficulty of establishing the basic content to be taught, difficulties related to the integration of lighting teaching into design practice, main deficiencies in learning, and the increasingly present need to develop multidisciplinary skills in students.

4. Conclusions

The analysis of the contents present in the selected articles showed that, despite the difficulty in determining exactly the content that should be taught in the field of lighting for future professionals linked to the production of built space - due to the complexity and wide variety of themes that make up the practice of lighting - it was possible to identify apparently essential contents to be addressed, such as: the need to understand the behavior of light and its interactions with the built environment, including the ability to establish compositional and symbolic relationships; technical knowledge of the functional aspects of light and comprehension of available lighting technologies. At the same time, themes that were incorporated into lighting teaching were recognized, especially those related to human health and environmental sustainability, for example: the integration of natural light and electric light; sustainability and energy conservation in lighting design; user's relationship with lighting; integrative lighting - human-centered lighting; lighting on an urban scale (including the interface with landscape planning), in addition to the increasingly present need to deepen the teaching of computer simulation in view of the dissemination of its use by students and

professionals. Common points in discussions about teaching lighting are based on the inherent complexity of teaching lighting, arising from the multidisciplinarity present in the act of lighting. In this way, many of the paths pointed out by researchers for the educative approach include an educative practice that enables multidisciplinary practice; the understanding of the interaction of light with the architectural space – both in terms of performance and in compositional and symbolic terms – that promotes the understanding of new technologies and that also considers the development of personal skills necessary for professional practice.

PO142

FUNDAMENTAL STUDY OF METHODS FOR PREDICTION THE BRIGHTNESS OF VISUAL OBJECT BY USING THE STANDARD DEVIATION OF LUMINANCE LOGARITHM

Suzuki. N.[1], Maruyama, H.[1], Kozaki, M.[2], Hirate, K.[2], Ma, Y.[2]
[1] ENDO LIGHTING CORP., Tokyo, JAPAN,
[2]The University of Tokyo, Tokyo, JAPAN
n_suzuki@m1.endo-lighting.co.jp

Abstract

1. Motivation, specific objective

Many researchers have done research of spatial brightness to evaluate the brightness of the whole space using quantitative scales. However, usually designers decide the spatial brightness by the brightness of the visual object by illuminance distribution and/or luminance distribution, since designers don't have (or don't know) a useful spatial brightness index. Aim of this study is to propose an easily predicted method of brightness of the visual object using standard deviation of luminance logarithm, which probably can be applied to predicting spatial brightness as well.

2. Methods

Two experiments were conducted; the fundamental experiment is to verify the possibility of brightness of the visual object using the standard deviation of luminance logarithm and the second experiment is to verify the adaptability in real space.

The first experiment was conducted with 20 subjects aged 20 to 60(males and females) using seven rating scale of semantic differential method for brightness of visual object (luminaires, ceiling, wall, floor) and the whole space and four rating scale for glare of them. The experimental condition was 20 types: ten lighting conditions and two types of reflectance of the wall (white and gray).

The second experiment was conducted with 20 subjects aged 20 to 50 at six real spaces with different range of luminance distribution. i.e., office, entrance, others. Evaluation methods are the same with the first experiment.

3. Results

The analytical values were defined as following; LL is the luminance logarithm of each pixel. ALL is an average luminance logarithm, SDLL as the standard deviation of luminance logarithm, BVT1 is the brightness of visual object 1 calculated using LL divided by SDLL, BVT2 is the brightness of visual object 2 calculated using LL multiplied by Napier number to the power of SDLL.

The fundamental study showed that several proposed indexes had high correlation with the subjects' evaluations. The following relationships had high correlation coefficient; evaluation of the brightness of visual object with LL (0,74), BVT1(0,72), and BVT2(0,73); evaluation of spatial brightness with BVT1(0.76); glare with BVT1(0,78), LL(0,57) and BVT2(0,44). The following relationships had high correlation coefficient in the results of experiment in real space; evaluation for the brightness of visual object with LL(0,58), BVT1(0,43), and BVT2(0,55); glare with BVT2(0,63),The others were LL(0,16) and BVT1(0,18).

4. Conclusions

The two experiments showed the possibility of an easy prediction of the brightness of the visual object by luminance logarithm multiplied by the Napier number to the power of the standard deviation of luminance logarithm. The brightness of the visual object was calculated

for each pixel of the luminance image and the brightness of the space was predicted from the average value. It was shown that glare could also be predicted in the same way using BVT2. This can be used to predict the lighting environment by lighting simulation in BIM and other applications, and to optimise the control of brightness and energy harmoniously by sensing with a luminance camera.

PO145

ACHIEVING ENERGY SAVINGS AND STIMULATING COMMUNICATION IN OFFICE SPACES USING TASK AMBIENT LIGHTING

Ueno, S.[1], Mukai, K.[1], Fuwa, M.[1], Kawase, Y.[1] Uchida, T.[1]
[1] Panasonic Corporation, Kadoma, JAPAN
ueno.saori@jp.panasonic.com

Abstract

1. Motivation, specific objective

In Japanese offices, lighting is commonly planned by using the general lighting, which employs only base light. It is used not only in "office spaces" designed for individual work but also in "communication spaces" where multiple people hold discussions. Typically, the method uses lighting with a colour temperature of 5000 K and desktop illuminance of 750 lx. However, the efficient use of energy is crucial to counter the increasing costs of electricity. Therefore, lighting is being reassessed to reduce energy wastage and create a sustainable society. Nevertheless, general measures such as reducing the brightness of lighting could elicit discomfort. Thus, both energy efficiency and comfort must be ensured.

Certain advanced offices are increasingly adopting office designs that incorporate Activity Based Working (ABW). Owing to the post-pandemic increase in remote working, improving the quality of communication has become the focus of workspace design.

Our interviews with lighting planners revealed that communication spaces require several important elements. First, the space must promote a calm and relaxed atmosphere. Second, it must ensure that the facial features of seated employees (sitting view) are adequately visible. Third, it must promote a casual, informal atmosphere unlike typical office space. Finally, it must ensure visual prominence when workers look at the communication space from a passageway (distant view).

Based on the above requirements, task ambient lighting (TAL) is one of the most suitable for use in offices. It is known to save significant amounts of energy compared to general lighting. However, most studies on TAL focus on workability and glare, in addition to whether it promotes concentration. In other words, its effect on communication remains unclear. Accordingly, this study aims to clarify whether using TAL instead of general lighting can stimulate communication, in addition to saving energy.

2. Methods

The experiment was conducted in a 10m×7m laboratory room with a 1.8m x 0.9m table (wooden, 50% reflectance) and four chairs. The laboratory consists of three spaces, i.e., a communication space, passage, and individual workspace. In the communication space, general lighting was combined with variables of desktop illuminance (500lx/750lx) and correlated colour temperature (3500K/4000K/5000K) to subject the space to four different lighting conditions. Meanwhile, TAL was combined with variables of desktop illuminance (500lx/750/1000lx), correlated colour temperature (3000K/3500K/4000K/5000K) and light distribution (wide /medium/narrow) to obtain 15 different lighting conditions. The ambient illuminance of TAL was one-third of the desktop illuminance. A long base light fixtures and a spotlight were used for lighting.

Subjects were divided into groups of 3 to 4 people. Observation positions were set in two patterns: looking at the area around the table from the passage (distant view) and looking at the area sitting on a seat (sitting view). The subjects were 22 office workers, which comprised 17 men and 5 women. The age of the subjects ranged from 26 to 64, with an average age of 43.

3. Results

To meet the requirements of the communication space for the sitting view (relaxed atmosphere and adequately visible facial features) and for the distant view (casual atmosphere and visual prominence), combinations of different lighting conditions were found to be important. Specifically, a slightly smaller illumination range for the entire desktop (medium light distribution), a desktop illuminance of 750lx or less, and a correlated colour temperature of 3500K or less was found to be the optimal setting, which can also realize energy saving by approximately 45% compared to general lighting.

If the desktop illuminance is 500lx or 750lx (TAL), a low colour temperature environment (3500K/3000K), which is generally not used in offices, is acceptable. However, a low correlated temperature(3500K/3000K) does not induce a significantly calmer atmosphere compared to a high correlated colour temperature (5000K/4000K). Nevertheless, TAL with low correlated temperature (3500K /3000K, 750lx/500lx), results in greater sense of unity among employees compared to general lighting with high correlated temperature (5000K, 750lx).

The ambient illuminance (167lx) with TAL is lower than that of general lighting (750lx). Therefore, it is thought a lower correlated colour temperature increased comfortability. This result can be attributed to the fact that the main task in communication spaces is conversation. Thus, employees accept lower correlated colour temperature. In contrast, they require higher correlated colour in individual workspace, in which the main tasks are visual in nature.

In addition, when the face illuminance is 250lx or more with TAL, favourable evaluations of facial appearance can be obtained. However, adequate facial visibility was absent in the case of narrow light distribution of task light.

However, this evaluation is limited to TAL using spotlights as task light; lighting conditions such as that provided by pendant lights with high luminance on the light emitting surface were not confirmed. Thus, further investigation is required in the future.

4. Conclusions

We were able to clarify the acceptable TAL setting values in office communication spaces. Considering the requirements of a communication space from the sitting view and distant view, TAL with a correlated colour temperature of 3500K or less, medium light distribution, and a desktop illuminance between 750lx and 500lx was found to be effective. By satisfying these set values, we can create the impression of a space that stimulates communication and a sense of unity between workers, while reducing energy consumption compared to the general lighting method.

PO150

STUDY ON THE INFLUENCE OF DIMMING SWITCH STRATEGY TO LABORATORY ANIMALS

Wang, L.[1], Zhao, H.[2]
[1] Architectural research and Design institute of Tsinghua University, Beijing, CHINA, [2] Taicheng Purification Technology Engineering Co. Ltd, Jinan, CHINA
forgeter916@163.com

Abstract

1. Objective

Laboratory animals are animals that have been artificially bred and bacteria-free, with clear genetic background or source, and are used for scientific research, teaching, production, and testing. Progress in life science cannot be made without the contribution of laboratory animals which play an irreplaceable role as a "human surrogate", especially in medicine research. In order to obtain accurate, real and reliable data and reduce the interference factors caused by the animal feeding process, it is necessary to strictly control the quality of laboratory animals and raise them in a barrier environment which is the use of sterile isolation devices to maintain a sterile state or no foreign pollutants. In the barrier environment, laboratory animals live 24x7h in an artificial light environment, therefore, it is critical to create a healthy light environment for the laboratory animals. The conventional lighting methods of experimental animals adopt room general lighting, constant illumination, and daily timer switch. Because the process of switching the lamp causes the change of illumination and brightness in the space, it is a kind of light change stimulus to experimental animals. In this paper, the mice was taken as an example to evaluate the degree of stimulation of light changes on mice, and find appropriate lighting control means to minimize the adverse stimulation of lighting to experimental animals.

2. Methods

Body temperature, heart rate and respiratory rate were selected as indicators to measure the stress response of mice to changes in the light environment. The test subjects were 5 healthy adult mice of the same batch, and the test environment was a barrier animal lab where the mice were located in Individually Ventilated Cage (IVC) with horizontal illumination of 20lx and colour temperature of light source of 3300K. The space lighting was LED with dimming and remote control. First, in normal switch mode, the body temperature, heart rate, and respiratory rate of mice were tested 10 minutes before and after turning the lights on and off. As contrast modes, under the premise that other environmental parameters do not change, the light on mode was changed to gradient mode, and the luminous flux output of the lights were continuously adjusted from 0% to100% within 30 seconds, 60 seconds, 120 seconds, 180 seconds and 300 seconds respectively, and the reverse dimming mode was adopted when the lights off. Each mode was tested for 3 days, and after the end, it returned to the normal switch mode for 3 days. Subsequently, the experiment of the next mode was performed. In each mode, the mice were tested for physiological indicators 10 minutes before and after turning the lights on and off.

3. Results

In the normal switch mode, after turning on the light, the heart rate of the experimental mice rose significantly, reaching the highest peak within 15 seconds which was 173% of a calm state. It then dropped, and after about 200 seconds, the average heart rate resumed its active state. Similarly, after turning on the light, the respiratory rate of the experimental mice increased sharply, reaching the highest peak within 30 seconds which was 214% of a calm state. It then declined, and after about 150 seconds, the average respiratory rate regained its active state. The body temperature went up 0.4℃ in average within 5 minutes after turning on the light. In the light off mode, the changes to heart rate and respiration rate were similar to

that of the normal switch mode, however, the peak value were lower than that of the normal switch mode. And there was no significant change in body temperature.

After turning on the light in dimming mode, the maximum heart rate and respiratory rate of the experimental mice during switching on and off were lower than those in the normal switch mode. In 60s dimming mode, the peak heart rate was 148% of the calm state and the highest respiratory rate was165% of the calm state, lower than the physiological indexes in normal switch mode and 30s dimming mode. The indicators of 120s, 180s and 300s modes were close to those of the 60s mode with no obvious change. In the dimming mode, the degree of agitation of the mice was reduced evidently after the change of light environment.

4. Conclusions

From the above experiments, it can be seen that the mice are sensitive to variations in light. The rapid change of lighting environment in the barrier environment will cause pronounced stress reaction of the experimental mice, which is reflected in the change of physiological indicators of heart rate and respiratory rate. This change is away from the goal of maintaining a consistent state of laboratory animals. By adopting dimming mode to avoid transient changes of light environment, the degree of stress response of the mice can be improved noticeably. After analysing the test results under five dimming modes, the threshold and range of lighting conversion in barrier environment of mice breeding were obtained, which provided suggestions and references for the lighting environment design and operation of laboratory animal buildings.

PO152

PERCEPTION OF LIGHT QUALITIES – A DESIGNED STUDY ON LIGHT SOURCES IN COMBINATIONS

Wendin, K.[1,2], Hiller, C.[3] and Enger J.[4]
[1] Kristianstad University, Kristianstad, SWEDEN, [2] University of Copenhagen, DENMARK, [3] RISE Research Institutes of Sweden, Borås, SWEDEN, [4] University of Arts, Crafts and Design, Stockholm, SWEDEN
karin.wendin@hkr.se

Abstract

1. Motivation, specific objective

The design of indoor environments is important for comfort, well-being and, in the long run, health. The qualities and design of the lighting significantly contribute to the overall room experience and are dependent on the properties and performance of light sources. To achieve an attractive light environment with desired atmosphere, physical requirements should be fulfilled, however human perception must be considered. Further, many light environments are lit with different light sources that varies in placement, light distribution, and colour temperature, which all have impact on the visual quality of a space.

Two fundamental and interacting factors for the perception of light character are light level and contrasts. Contrasts can be achieved through a direct light distribution creating distinct light, shadows, highlights, and reflections/sparkle in different materials. The variation of perceived contrast is directly linked to the properties and the placement of the light source and may result in either diffuse or distinct transitions between highlighted and shaded areas. Colour temperature is important for perceived light qualities and overall experience, for example the perceived light colour. To evaluate perception in an objective way, analytical sensory methodology can be used. Sensory analysis of lighting products is new, however previous studies have shown that it can be applied to the perception of lighting.

The specific objective of this study is to evaluate, by sensory analysis, the perception of combinations of two different light sources varied according to a factorial design. In all, 16 different combinations were studied.

2. Methods

Light sources: 16 different combinations of two light sources were varied according to a factorial experimental design. The design factors were the following: light sources (direct/omnidirectional), placement (general/point), and colour temperature (2700K/4000K). All the lighting products were white LED lightings found in retail stores. The combinations of light sources were installed in separate test booths (ISO standard) equipped with different items such as a frame, a magazine and a golden bow.

Method: The evaluation method was descriptive analytical sensory analysis, a non-subjective method. Analytical sensory methods aim to obtain objective assessments of perception, where personal preferences and hedonic responses are not considered. The assessments are performed by panellists who are selected for their well-developed subtle senses and then trained for each occasion of evaluation.

In this study the panel consisted of 8 panellists who individually assessed each combination of the two light sources. The evaluation was performed in triplicate and in a randomized order. The training of the panel included the establishment of a set of sensory attributes, i.e., the light qualities, to be evaluated, as well as training on evaluation scales for each attribute. After the training the actual assessments took place.

Statistics: Data was analysed by descriptive statistics. To find out whether the lighting combinations sets differed significantly regarding the evaluated attributes, two-way ANOVAs

(analysis of variance) were performed with products and panellists as fixed factors. After the ANOVAs, Tukey's pairwise post hoc tests were applied ($p<0.05$). A principal component analysis (PCA) was carried out to give an overview of the results.

3. Results

The resulting data was clearly divided into four different clusters. According to the PCA plot, PC1 and PC2 explained 88.6% of the variation of the resulting data. The clusters could mainly be divided between the describing attribute "distinct" on one side and "diffuse" on the other, which refers to the design factor light sources being direct or omnidirectional. Further, the placement of the light sources had a significant impact.

- The first cluster that could be described as the most distinct, and consisted of directional light sources, both as point and general lightings. This cluster could also be described as having sharp and distinct multiple shadows, and further to give reflections.
- The second most distinct cluster consisted of directional light sources as point lighting and omnidirectional sources as general lighting. The shadows were sharp, but the reflections were less distinct than in the first cluster.
- The third cluster consisted of omnidirectional light sources as point lighting and direct light sources as general lighting. This cluster could be described as being more diffuse than distinct, having less sharp shadows, but still clear reflections.
- The fourth cluster was the most diffuse, having unsharp shadows and less reflections. It consisted of omnidirectional light sources both as point and general lighting.

Looking into the different clusters, significant differences could be found between different combinations of light sources, mainly when it came to shadows. Further, the division of the four clusters were not related to the assessment of the attribute warm light colour. However, significant differences between the combinations could still be found, which were related to the design factor colour temperature. As expected, the least perceived warm light colour were found in combinations where both point and general light sources were 4000K and the warmest light colour were perceived in combinations where both light sources were 2700K. For the combinations of 4000K and 2700K light sources, the combination where the point light source was 2700K and the general was 4000K, was evaluated as warmer than the opposite combination of light sources.

The panel evaluated, consequently, the combinations of light sources based on the design factors and where the main design factor was directional/omnidirectional light sources.

4. Conclusions

All design factors had significant impact on the perceived light qualities. Of main interest are the combinations directional and omnidirectional, but also placement and colour temperature are of interest. It could be concluded that the light distribution of the point lighting is the most decisive for whether the light is perceived as diffuse or distinct. Direct light sources give light perceived as distinct, which is reinforced if both point and general lightings are direct. In addition, the point lightings have a greater impact on perceived light colour than the general lighting.

PO154

REPRODUCTION OF DAYLIGHTING BY LED LUMINAIRES SIMULATING ILLUMINANCE AND CORRELATED COLOUR TEMPERATURE FLUCTUATION: VERIFICATION OF PHYSIOLOGICAL AND PSYCHOLOGICAL STRESS

Xiang, L.[1], Akuzawa, Y.[1], Oe, Y.[1], Yoshizawa, N.[1], Nakaso, M.[2], Kaiho, K.[2], Shinohara, N.[3]
[1] Tokyo University of Science, Chiba JAPAN, [2] Nikken Sekkei, Tokyo, JAPAN, [3] Tokai University, Kanagawa, JAPAN
7122546@ed.tus.ac.jp

Abstract

1. Motivation, specific objective

Daylighting is well known for improving people's health and comfort and has been actively introduced in interior lighting. However, it is difficult to secure sufficient daylight in certain building locations. In recent years, LED luminaires that can be easily controlled with a wide range of light colours and intensities have been developed, and it is possible that their characteristics can be made closer to those of daylight. It is necessary to verify whether the same effect can be achieved using LED luminaires for interior lighting as a substitute for daylight. One of the characteristics of daylight is that its colour and intensity constantly change with time and weather. This study examined a method for reproducing correlated colour temperature (CCT) and illuminance fluctuations of daylight using LED luminaires. In addition, the physiological and psychological effects on humans were compared in an environment with daylighting and another where daylight fluctuations were reproduced by LED lighting fixtures.

2. Methods

To reproduce daylight fluctuations, an experiment was first conducted from August to November 2021 using daylight as the light source (hereafter referred to as the daylight experiment). The illuminance and CCT data in front of the eyes were measured every 15 seconds using a spectroradiometer, and the time-series fluctuation data were obtained. From April to May 2022, a controlled experiment was conducted using LED luminaires that reproduced the illuminance and CCT obtained in the previous experiment (hereafter referred to as the reproduction experiment).

The method of reproducing the daylight fluctuation with LED luminaires is as follows. Since the LED luminaires used in this experiment were controlled by multiple LED chips, the illuminance and CCT were first measured by controlling each chip. The prediction equation relating the output of each chip to illuminance and the prediction equation for CCT using the average values of the x and y values on the chromaticity diagram of each chip were derived. The dimming data at 1-second intervals were generated by spline interpolation of the data at 15-second intervals obtained in the daylight experiment, and the closest illuminance and CCT at each time were extracted from the aforementioned equations to reproduce the daylight fluctuations.

Both experiments were conducted for 20 minutes and took place in a square-shaped 7.29m² space with desks and chairs. Two subjects were seated in a chair and were asked to perform an 8-minute semantic association task after a 6-minute dark adaptation and a 2-minute adaptation for the experimental environment. Before and after the task, the subjects were asked to complete a psychological questionnaire within 2-minutes. The physiological responses of the subjects were captured using wearable heart rate sensors during the experiments. The subjects were 20 students in their twenties with normal colour vision.

3. Results

The illuminance and CCT fluctuations were broadly categorised, and statistical tests were used to determine trends. A total of 35 paired samples were classified into four patterns according to the presence or absence of illuminance and CCT fluctuations, and the trends of increase and decrease for these fluctuations:(1) illuminance fluctuations: present, CCT fluctuations: present, directional fluctuations (two paired samples); (2) illuminance fluctuations: present, CCT fluctuations: present, irregular fluctuations (seven paired samples); (3) illuminance fluctuations: present, CCT fluctuations: absent, directional fluctuations (seven paired samples); (4) illuminance fluctuations: present, CCT fluctuations: absent, irregular fluctuations (nineteen paired samples). Since the number of samples was quite small, pattern 1 was considered statistically meaningless and excluded from the present study.

Physiological indices and psychological evaluations were examined to compare the results of the two experiments. For physiological indices, the measured heart rate and high-frequency components were extracted, and Wilcoxon signed-rank tests were conducted on the differences before and after the task, respectively, to determine the stressing tendency ($p<0.05$). For psychological evaluations, a factor analysis was carried out, and a total of 55 evaluation items were classified by varimax rotation and maximum likelihood estimation, extracting a total of six factors: brightness, spaciousness, workability, stability, uniformity, and warmth. The scores for each factor were tested using Wilcoxon signed-rank tests to determine the tendencies ($p<0.05$). There were no significant differences in patterns 2, 3, and 4, either physiological or psychological effects. Comparing the absolute values of the factor scores' means, pattern 2 tended to be more spacious in the reproduction experiment than in the daylight experiment.

4. Conclusions

For reproducing daylighting, LED luminaires successfully simulated the fluctuation with controlled illuminance and CCT. In all fluctuation patterns, it was found that there were no significant differences between the daylight and reproduction experiments in terms of physiological and psychological effects. Therefore, it was determined that it is possible to reproduce daylighting with light colour and intensity fluctuation using LED luminaires in interior lighting environments when performing the association task. As daylighting differs from LED luminaires in various aspects, other factors, such as the incident direction of daylight, will be considered in the next phase, and the reproduction of daylight using LED luminaires will continue to be investigated.

PO157

PSYCHOLOGICAL AND PHYSIOLOGICAL ANALYSIS ON THE EFFECT OF PEACEFULNESS OF MIZUKAGE VIDEOS

Yu, H.[1], Akita, T.[1], Sano, N.[1]
[1] Tokyo Denki University, Tokyo, JAPAN
hnwind@mail.dendai.ac.jp

Abstract

1. Introduction

"Mizukage", which is the subject of this research, is "reflected and flickering light reflected on the walls and ceilings of places with water surfaces" such as near rivers and ponds. From previous study, it can be seen that there are differences in the psychological effects of Mizukage on people depending on the period of fluctuations and the light-dark. In addition, it is considered that the viewing angle of the wide-field video affects the psychological effect. However, there are no studies on viewing angle in previous studies dealing with Mizukage. The purpose of this study is to confirm the effect of psychological evaluation based on the fluctuation period and viewing angle of Mizukage, and the peacefulness caused by changes in brain waves.

2. First experiment

2.1 Outline

The purpose of the first experiment was to examine the relationship between the kind of Mizukage video and the peacefulness depending on the playback speed. The first experiment was conducted in a 2200㎜×2000㎜ booth space covered with white walls. The distance between the subject and the wall projected on the projector was 2000㎜. The experimental factors were the video type (roughness-small, medium, large) and playback speed (0.25 times, 0.5 times, 1 times). The video used was a picture of the actual Mizukage, and the screen sizes were all 360㎜ x 650㎜ (viewing angle 5.7 °x 9.2 °). The subjects were 7 males and females in their 20s. First, in order to adjust the dark adaptation of the subjects, the subjects were allowed to rest for 1 minute. After that, the subject opened his eyes, shown the mizukage video projected on the wall from the projector for 15 seconds, and then made a subjective evaluation. This was repeated 9 times. To prevent the order effect, the Latin square method was used. Subjective evaluation was evaluated using a 7 scales SD method with 23 adjective pairs words. Finally, the subjects were asked to evaluate the presence or absence of peacefulness in two alternatives, and each video was rearranged in the order that seemed to be peacefulness.

2.2 Analysis and Results

As a result of the presence or absence of peacefulness, all the subjects answered that video 6 (0.5 times speed, medium roughness) had a peacefulness, and video 2 (1 times speed, large roughness) had no peacefulness. As a result of evaluation of peacefulness, it became 1, 2 and 3rd in order of 0.5 times speed, 0.25 times speed and 1 times speed in the roughness. A 3-way ANOVA was performed based on the type of video, playback speed, and subjects. Video 6 was rated "Nature" and Video 2 was rated "Far". The speed was rated as "unnatural" as it slowed down.

3. Second experiment

3.1 Outline

The purpose of the second experiment is to investigate the psychological and physiological effects of the peacefulness caused by the fluctuation of Mizukage on the viewing angle. The experimental factors were the video type and viewing angle (18.3 ° x 10.5 ° [video size 740mm x 1320mm], 9.2 ° x 5.7 ° [650mm x 360mm], 4.5 ° x 2.7 ° [315mm x 315mm]). As the videos to be used, the video 6 (0.5 times speed, medium roughness) evaluated as having the most peacefulness obtained in first experiment and the video 2 (1 times speed, large roughness) evaluated not having the peacefulness were used. The subjects were 9 males and females in their 20s. In the second experiment, subjects were allowed to dark adaptation for 1 minute, then shown a video for 1.5 minutes, and filled in an evaluation sheet. This was repeated 6 times. The content of the subjective evaluation is the same as in first experiment. The electroencephalogram was measured at 7 locations of Cz, T3, T4, P3, P4, O1, and O2 from the start to the end of the experiment according to the international 10-20 method.

3.2 Analysis and Results

As a result of the presence or absence of peacefulness, all the subjects answered that viewing angle of 4.5°×2.7°and viewing angle of 18.3°×10.5°of video 2 had no peacefulness, and that of video 6 had viewing angle of 5.7°×9.2°with peacefulness. From the above results, it was found that the viewing angle of 5.7 ° × 9.2 ° is the most peacefulness for both videos 2 and 6. A 3-way ANOVA was performed based on the types of videos, viewing angles, and subjects. It was found that there was a significant difference in the subjective evaluation of Mizukage depending on the viewing angle.

Using the effective electroencephalogram data of 6 of the 9 people measured, the power values and ratios of δ, θ, α, and β waves were determined by FFT. A 3-way ANOVA was performed for the ratio of each band based on the type of videos, viewing angles, and subjects. There were significant differences in viewing angles between P3, P4, and O2. P3 and P4 correspond to somatosensory cortex and O2 corresponds to visual cortex. A narrow viewing angle of 4.5 ° × 2.7 ° has a large proportion of P3 and P4 α waves. Since α waves are seen in a resting state or when trying to concentrate, we speculate that the fluctuation of Mizukage is caused by changes in somatic sensations. In O2, β waves are also observed. This indicates that visual brain activity is being performed. Meanwhile, in viewing angle 9.2 ° × 5.7 ° which is the moving image size at the time of photographing and the wide viewing angle 18.3 ° × 10.5 °, the ratio of the O2 θ wave is large. Since the θ wave is seen in the sleep state, it is presumed that it is in a deep relaxed state. Based on the above results, it was found that the viewing angle needs to be adjusted in order to obtain peacefulness with Mizukage because the brain activity changes depending on the viewing angle.

PO159

IMPACTS OF LED TEMPORALLY MODULATED LIGHT ON ATMOSPHERE PERCEPTION

Zhao, X. [1,3], Li, M. [1,2], Hou, D. [1,2], Lin, Y. [1,2,3], Xu, W. [1,2]
[1] Institute for Electric Light Sources, Fudan University, Shanghai, CHINA, [2] Institute for Six-sector Economy, Fudan University, Shanghai, CHINA, [3] Institute of Future Lighting, Academy for Engineering and Technology, Fudan University, Shanghai, CHINA
ydlin@fudan.edu.cn; weixu@fudan.edu.cn

Abstract

1. Motivation

The widespread use of LED lighting systems has raised concerns about the effects of temporally modulated light on indoor lighting in recent years. Such modulated light can lead to inappropriate changes in the visual perception of the lighting environment, commonly referred to as the stroboscopic effect. Stroboscopic Effect Visibility Measure (SVM) is a new metric that can predict the visibility of the stroboscopic effect in general lighting applications. Existing guidelines and studies on the stroboscopic effect mainly focus on its effects on human health and well-being, while a relationship between the SVM and atmosphere factors has been less studied. Thus, a psychophysical experiment has been conducted to investigate the atmosphere perception as LED temporal-modulated lighting varied at different SVM levels.

2. Methods

Participants were randomly recruited from Fudan University between 19 and 23 years old, with an average (±std) age of 20.80 (±1.17). There were 10 participants in total, including four males and six females. All subjects met the conditions of normal vision (e.g., no color blindness, color weakness, or a family history of eye disease) and health requirements (e.g., no epilepsy or a family history of epilepsy, or suffering from migraine and headache, no other severe disease).

The experiments were conducted in a lighting lab, and the room size is L 3.1 m × W 1.95 m × H 2.02 m, arranged as a general office. A desk and chair were placed in the room, with a beige sofa and tea table opposite the desk. The walls and ceiling were white, except for a black carpet on the floor. This experiment used a power amplifier (AIGTEK ATA-3040) and a waveform signal generator (ALLROOT GD400) to drive the LED luminaire to generate the six lighting conditions at different SVM levels, in which the lighting waveform was set as the sine wave. The SVM levels are 0.060, 0.500, 1.000, 1.500, 2.500, and 3.868. The illumination, CCT, and Ra measured at the desk surface were 500 lx, 4000 K, and >85, respectively.

In this experiment, a visual sensory semantic scale was used for each lighting stimulus. After a 5-minute adaptation period to the environment, participants were asked to assess the environment using 16 atmosphere terms based on a seven-level scale, including uncomfortable, spatial, tense, lively, pleasant, inspiring, formal, glaring, blurry, tranquil, satisfied, stimulating, flickering, relaxed, acceptable, lethargic.

3. Results

First, the Factor analysis was adopted to examine the effect of the SVM metric on atmosphere perception. The results showed that the 16 atmosphere terms could be grouped into four dimensions: tenseness, coziness, liveliness, and detachment, which accounted for 89.742% of the total variance.

Second, ANOVA analysis was performed using the SVM levels as independent variables and the normalized average scores of the four dimensions as dependent variables. The LED temporal-modulated light significantly influences the atmosphere perception, mainly referring

to the environmental detachment ($\eta_P{}^2$ > 0.1379; $p < 0.01$). Higher SVM levels led to increased detachment and tenseness and decreased liveness in atmosphere perceptions.

After that, a regression analysis was conducted to explore the relationship between the SVM metric and the normalized average score of detachment dimension ($Z_{\text{detachment}}$). The results showed that the detachment dimension of the atmosphere varied significantly as a logistic function of the SVM metric (R^2 = 98.4%), and the corresponding threshold for perception of "just detachment" ($Z_{\text{detachment}}$ = 0) was SVM = 1.181.

4. Conclusions

In this study, the effect of the SVM metric of LEDs on atmosphere perception was investigated. It was found that the four dimensions of atmosphere perception were obtained and identified as tenseness, coziness, liveliness, and detachment for different SVM levels. Furthermore, the SVM metric had a significant impact on the detachment dimension of atmosphere perception: with the increasing SVM levels, participants would report higher scores for the flickering terms. The logistic function highlights the relationship between the SVM metric and the detachment dimension, with perception thresholds of SVM = 1.181, indicating that the visible stroboscopic effect from LEDs could cause detachment perception for lighting. These findings suggest that the SVM limits for LED allowable modulation should be treated with great caution in practical lighting applications.

PO161

AN ENERGY EFFICIENT HUMAN CENTERED LIGHTING FOR OPEN PLAN OFFICES WITH COMFORT CRETERIA

Aliparast, S.[1], Onaygil, S.[1]
[1] Energy Institute of Istanbul Technical University, Istanbul, TURKIYE
Aliparast17@itu.edu.tr

Abstract

1. Motivation, specific objective

Light-emitting diode (LED) is today's most energy-efficient and rapidly-developing lighting technology. The advent of LED lighting has improved relationship of light and human body system. The influence that light has on our bodies reaches far beyond the visual effects. In fact, the varying light levels are at the heart of a human’s internal clock, also known as the circadian rhythm. Light and darkness cycle of sun controls our hormone production, thus influencing our sleep, alertness, mood, memory and performance. New concepts of light-measurement strategy and tricks taking account to the operation of complex photoreceptive inputs to the non-visual responses which are suggested to design a Human Centric Lighting (HCL) by researchers, architectures, lighting designers, lighting manufacturers, and engineers.

Office workers spend more than half of their awake time at work on weekdays. Good work efficiency consists of a functional and comfortable working environment. Therefore, it is important that non-visual effects of light be included into considerations for lighting designs. Circadian effectiveness is used as a synonym for the potency of light to provoke positive, non-visual outcomes in humans. So, HCL usually have to deal with lighting parameters regarding examination of luminaires for efficient lighting solution at offices to enhance performance of users in a daylight non-access offices. In this study, it is aimed to investigate the effects of lighting quality criteria and values, which are taken as a basis in HCL evaluations, on the performance of office workers.

2. Methods

This research is held on the office with dimensions of 4.9×4.6×2.8 meters which is located in Energy Institute of Istanbul Technical University with geographic location of 41°06'27.7"N 29°01'50.9"E. The horizontal working plane is on 0.8 height of room floor on the desk and horizontal illuminance level (E_H) is defined as well. The reflectance values of the office 40%, 90%, and 90% for the floor, walls, and ceiling, for chairs 2.5%, desks and drawers are 86% respectively.

A computer simulation methodology is implemented to Direct and Indirect suspended linear (DISL) and Direct suspended linear (DSL) Luminaires with 3800K colour correlated temperature (CCT) to meet the worker’s requirements to illuminance level on vertical and horizontal plane. The selected luminaires are ignored being tuneable white lighting with different CCT as variables and its HCL effect. Vertical illuminance level (E_V) and dynamic luminaire mounting height were evaluated accordingly.

- DIALux Evo and Microsoft Excel are used for simulation model which is conducted for open plan office. Calculation surface to measure the illuminance levels in a horizontal calculation surface with dimensions of desks 0.8×1.3 meters, on the working plane at 0.8 m above finished floor level. Besides, calculations to measure E_V is proposed on 1.2 m above finished floor on human eye level height and direction of view.

- The circadian stimulus (CS) metric is a physiologically relevant measure of circadian effectiveness in lighting regarding; UL 24480, and equivalent melanopic lux (EML) is referred to CIE S 026:2018 and DIN SPEC 5031-100 are corresponding evaluation scheme for CS and EML for proposing a HCL design. Regarding the standards,

required CS for office workers depends on the office hours is 0.3 and 0.4 for the highest productivity time zone of the day and it is defined higher than 240 for EML.

- ➢ Due to using CS calculator, inserting Spectral Power Density (SPD) of luminaires is needed. CS is calculated on LRC online calculator which is based on the E_V of the occupant's sight direction in the office. On the other hand, to access the EML, same SPDs are inserting to Melanopic Ratio (MR) calculator file to get the MR amount based on individual luminaire. The SPDs of the luminaires was measured experimentally between wavelengths of 380-730 nm at photometry and radiometry laboratory of Energy Institute of Istanbul Technical University. MR for DISL is 0.722 and for DSL is 0.651 regarding the MR calculator.

- ➢ The E_H of desk and E_V in eye level of occupant was evaluated in three alternative height steps as H_1:1.5 m, H_2:1.8 m, and H_3:2.3 m above finished floor on top of the desk and 1.2 m distance from the wall behind the occupant to obtain the CS minimum 0.3 and EML higher than 240. To clarify the results of simulation and experimental results, questionnaires and paper based eye tests are shared with office workers for 100 minutes. The answers to the survey questions will be evaluated with Wilcoxon test and chi square at SPSS software.

3. Results

- ✓ Simulation results are E_H on desk, E_V at occupant's eye level, CS, EML at each of three height scenarios for DSL shows: E_VH_1:532 lux, E_VH_2:524.66 lux, E_VH_3:561 lux and E_HH_1:1505 lux, E_HH_2:607 lux, E_HH_3:580 lux. Accordingly, CSH_1:0.303, CSH_2:0.3, CSH_3:0.314 and $EMLH_1$:346.33, $EMLH_2$:341.55, $EMLH_3$:365.211.

  Additionally, three height scenarios for DISL shows: EVH1:437.3 lux, EVH2:337 lux, EVH3:432 lux and EHH1:1100 lux, EHH2: 424 lux, EHH3:460 and CSH1:0.329, CSH2:0.3, CSH3:0.326 and EMLH1:315.755, EMLH2:243.314, EMLH3:311.904.

- ✓ Experimental data gathering continues, so it cannot be shared at this moment.

4. Conclusions

The proposed suspended luminaires with dynamic height in offices, helps to improve the CS and EML by focusing on working plane and office workers view direction. With these systems, the same lighting quality criteria can be achieved with lower luminous flux and therefore lower electrical power. Therefore, proposed HCL standards for open plan office workers enhance not only office workers' performance, but also suggests an energy efficient system.

PO164

INFLUENCE OF THE DENSITY OF THE MEASUREMENT AND CALCULATION GRID ON PHOTOMETRIC PARAMETERS OF INDOOR WORKPLACES

Dubnicka, R.[1], Mokran M.[1], Gasparovsky, D.[1], Janiga, P.[1]
[1] Department of Electrical Power Engineering, Faculty of Electrical Engineering and Information Technology, Slovak University of Technology, Bratislava, SLOVAKIA
roman.dubnicka@stuba.sk

Abstract

1. Motivation, specific objective

The illuminance level required to perform a particular visual task depends on the ability of the observer trying to perform the task. Obviously, this level varies from case to case and is affected by the age of observer. The international standard ISO 8995-1:2002(E)/CIE S 008/E:2001 provides detailed instructions for specifying lighting levels for specific visual tasks, including adjustments to some of the above factors. The illuminance level specified in this standard is defined by the maintained illuminance level E_m, which is a level that takes into account the maintenance factor to ensure that, through the use of the lighting system i.e. calculated respectively measured illuminance does not fall below this level. This open very important question towards to lighting design. The eye is tolerant (adapts) to relatively large differences, and a 10-20% difference in an illuminance may not be felt much. So does the accuracy of the calculation matter much? There are two main points why calculation accuracy of photometric parameters is important. The first is that cumulative errors quickly become serious errors. An acceptable error at each stage can become an unacceptable error overall. The second point is that someone has to pay to install the lighting system. If the calculations are wrong, so that 20% more luminaires are needed and 20% more electricity is consumed, both initial and operating costs will increase. Perhaps even more important is the comparison of competing in tenders, where the cheaper offer may be cheaper because the lighting system will provide less light, even if it is claimed to provide the same level of illumination. In the absence of accurate calculations, it is impossible to make a satisfactory judgment. The accuracy of the calculation depends on the input data available to the designer. Individual input data can affect the accuracy of the calculation at the grid point or the average illuminance. Calculation and measurement grid of control points must be created to calculate and verify the illuminance level at the location of the visual task, the immediate surroundings and the background. It is preferred to design the grid with approximately square cells, where the length to width ratio of the grid cells must be between 0.5 and 2.0. The strip near the walls, 0.5 m wide, is not included in the calculation area, except in cases where the place of the visual task is in this boundary area or extends into it. The calculation grid should match the measurement grid. The calculation software initially sets up the calculation grid automatically and often with such large sizes that subsequent verification will be very difficult. Therefore, the density of the calculation grid is important to avoid a mismatch between the calculation and simulation of photometric parameters caused by a large difference in the density of the measurement respectively calculation grid.

2. Methods

In order to determine the effect of a different number of control measurement or calculation points, rooms and luminaires were used at the validation lighting calculation software according to CIE 171. These model rooms contain different surface reflectance and luminaires with different luminous intensity distribution curves. Such a procedure be able to determine the dependence of illuminance level and uniformity of illumination under different conditions. In the designed rooms, the number of calculation points was increased multiple times and the effect on the simulated average maintained illuminance level was observed along with the uniformity. Spacing of points of the calculation grid were 2 times, 0.5 times, 0.25 times and 0.13 times compared to the original spacing 1m as dimension of square cell of the grid. In

order to verify the influence of the different density of the measuring grid, a field measurement of the photometric parameters on real installation of luminaires in the meeting room was performed. The indoor workplace had a simple geometry, but in contrast to the simulations, it also contained various objects such as office furniture, windows, etc.

3. Results

In the article, will be presented results of the relative change of the simulated and measured average illuminance level, uniformity of illuminance, maximum and minimum illuminance depending on the set of density of the calculation respectively measurement grid. Another output from the research work is the determination of the maximum density of the measuring grid, which is significant from the point of view of the photometric parameters by means of on-site verification on real meeting room with regard on stated conditions according to defined measurement gird.

4. Conclusions

This article is concerning to the issue of a suitable measurement and calculation grid for indoor working places. Based on the results presented in the paper, it is possible to prevent errors associated with different measuring grids. In practice the results can be used as a guide for lighting designers to prevent big errors at the level of design. Furthermore, in connection with results presented in this research work it is possible to specify a certain tolerance interval for designers, which must be assumed in the practice in various cases to be assumed with mitigating of errors at designing of lighting systems of indoor workplaces.

PO166

DESIGN AND IMPLEMENTATION OF SMART HOME CLOUD CONFIGURATION PLATFORM

Ping, Y.[1], **KeJia, F.[2]**

[1] Shaanxi University of Science and Technology, Xian, CHINA, [2] Shaanxi University of Science and Technology, Xian, CHINA,

1821390586@qq.com

Abstract

1. Motivation, specific objective

With the rapid development of the smart furniture industry, the scenarios and applications of smart home will permeate all aspects of people's lives. However, there are many kinds of smart home, and the lack of unified standards for communication methods, communication interfaces and communication protocols has brought great difficulties to the networking and interconnection of the home. At the same time, with the improvement of living standards, people are increasingly pursuing the visualization and humanization of smart home based on the pursuit of comfort.

Based on this, this paper builds a smart home system based on the cloud-side architecture, and designs and develops a general and interactive cloud configuration platform for smart home system on the cloud side, using the web end as the entrance of the human-computer interface of smart home. The personalized smart home scene can be quickly constructed by simply dragging and dropping the smart home device model controls, and the real-time display of the system operation status and device control can be realized.

2. Methods

In order to realize the unified access of home devices and the unified management of different devices in different scenarios in the system, it is necessary to provide a unified description for the devices in the system. In this system, the device model includes two types of devices: edge gateway devices and home sub-devices. The model of the edge gateway consists of basic information and interface information. The sub-device model includes basic attributes, access information, data attributes, and operation information.

For cloud configuration platform, the cloud configuration platform is composed of configuration editing system and configuration operation system. The user completes configuration editing in the configuration editing system, including page layout and equipment configuration. The device access and model establishment of the edge gateway and sub-equipment are realized through the communication interface. Finally, the configuration description file describing the configuration page and model configuration information is formed. The configuration editing system and configuration operation system are contacted through the configuration description file.

The configuration operation system includes three parts: real-time data display, data area and communication interface. When the edge gateway receives the equipment data information, it analyzes and converts the data, sends it to the configuration platform through the communication interface, and stores it in the data area after the platform analysis. Considering the actual needs, the data area uses MongoDB and Redis databases as the historical database and real-time database of the system respectively. The device data information uploaded by the edge gateway is first stored in the data buffer corresponding to the Redis real-time database, and is actively pushed to the configuration page by the backend through the WebSocket protocol to drive the real-time update of the configuration page data information. MongoDB serves as the main storage device for historical data in the historical database and provides query and analysis services. The Redis database inserts the data regularly.

3. Results

Taking the lighting system as an example, the system is tested and verified. After the user logs in to the system, the user enters the configuration editing system after creating a new configuration item. The user completes the room layout and lamp layout successively and completes the equipment configuration.

After editing, enter the configuration operation system. The interface of the operation system is shown in Figure 10. The data attributes of lamps include power, color temperature, fault status, switch status, and brightness percentage. When entering the system, the lamp is in the ON state, highlighted on the page, the brightness percentage is 80%, and the current power is 246; When the lamp is turned off, the edge gateway uploads the changed data attribute of the lamp, and the backend actively pushes the data value to the operation page to change the corresponding lamp attribute. At this time, the brightness percentage is 0%, the current power is 0, and it is displayed in gray on the page.

4. Conclusions

This paper designs and implements an interactive and visual cloud configuration platform for a smart home system based on cloud edge architecture, which is convenient for users. First, aiming at the management and networking of different devices, the device model is designed for the edge gateway and sub-devices in the system, and the cloud platform access process is designed; Secondly, the format of the configuration description file and the real-time database storage model are designed. The Redis publish/subscribe mode is adopted, and the data is actively pushed by the background through the WebSocket protocol, which improves the real-time data access speed. Finally, the platform is tested and analyzed, and the expected results are achieved.

PO168

IMAGE PHOTOMETRY FOR EVALUATING LIGHTING ENVIRONMENTS: IMPROVEMENT IN SPEED AND ACCURACY BY USING RAW FORMAT PHOTO DATA

Horiuchi, Y.[1], Miyake, H.[2], Yamaguchi, H.[3], Nishihara, S.[1] Yoshizawa, N.[1]
[1] Tokyo University of Science, Chiba, JAPAN, [2] Arup, Tokyo, JAPAN, [3] National Institute for Land and Infrastructure Management, Tsukuba, JAPAN
hory044apd@gmail.com

Abstract

1. Motivation, specific objective

The correct evaluation of brightness and glare in real space requires luminance distribution in the field of view. In general, image photometry is used to obtain luminance distribution in space.

The luminance dynamic range of the environment in which we live is extremely wide, amounting to more than ten orders of magnitude. However, a typical JPEG image lacks dynamic range, because each channel is represented by eight bits (256 shades). Therefore, the image photometry method requires multiple images with different exposures and data combinations. However, there is a disadvantage in that acquiring many images is time-consuming. It is desirable to shorten the time taken to capture daylight environment, as the latter fluctuates greatly over a short period of time owing to weather conditions. Decreasing the number of images captured also contributes to reducing the experimental time and data weight. It should further be noted that JPEG files are subject to irreversible modifications during development, which may result in inaccurate values. Therefore, by acquiring luminance from RAW data, the number of images can be reduced, since the range obtained from a single piece of data is wider and the images can be taken in a shorter period of time. Additionally, RAW data is highly reliable because the RGB values are linear with respect to the luminance input.

In this study, we verified the linearity of RAW data with respect to the luminance input and created a luminance calculation formula. After examining the reliable dynamic range of the data of each RAW file, we determined an ideal set of exposure sequences to evaluate the daylight environment and the extent to which the measurement time could be reduced.

2. Photographic Data Processing Process

To obtain luminance values from RAW files, RGB values must be converted to XYZ values. An overview of this process is provided below.

1) For each RAW file, acquire the RGB values and convert them into a matrix.

2) Obtain the values of shutter speed, f-stop, and ISO from each piece of Exif data, and calculate the Exposure Value.

3) Multiply each RGB value by 2 to the power of Exposure Value.

4) The various matrices in the series are combined into a single matrix by extracting a reliable part of each dataset.

5) Convert the matrix into XYZ values by multiplying the conversion matrix and saving in csv format.

3. Methods

In this study, we compared the measured XYZ values with the RGB values from the RAW data to confirm their linearity, calculate the conversion matrix, and check their reliability. For this purpose, a Macbeth colour chart was utilised, which was mounted on a box created to maintain uniform illumination on one surface. Six lights (DN Lighting TRH550ND-FPL) and a light manager (Panasonic NQ28841K) were used as the light sources (maximum illuminance on the colour chart surface was 29000 lx and minimum was 1200 lx). A Canon EOS 5D Mark III and a fisheye lens (SIGMA 8 mm F3.5 EX DG CIRCULAR FISHEYE) were employed for the photography. The luminance and illuminance on the Macbeth colour chart were measured using a luminance meter (CS160) and an illuminance logger (TR-74Ui), so that the XYZ values for each colour chart could be calculated from the illuminance.

4. Verification and Application

For each of the 24 colours in the Macbeth colour chart, a scatterplot was created, with the X-axis representing the $Y \div 2^{\text{Exposure Value}}$ of the XYZ values measured using a luminance meter and an illuminance meter, and the Y-axis representing the RGB values of the RAW files at different exposures and illuminance settings. The results show that the relationship is linear up to approximately y=14000, with y=2048 as the intercept, as was the case with any colour chart. The smaller the y value, the greater the effect of noise.

Following an examination of these results, the reliable interval of the RAW data was set as 2304–13500, and data in which all R, G, and B values were within this range was extracted. Multiple regression analysis using XYZ and RGB values yielded a conversion matrix. With the conversion matrix obtained, we created a luminance calculation formula to convert RGB values to XYZ values.

Comparing the luminance measured with the luminance calculated using this study's method, the average error was within 3%. As shown by the results, the reliable dynamic range of the data of each RAW file was greater than 2 to the power of 5, and we set 5 EV as the interval of the steps as the ideal set of exposure sequence for evaluating the daylight environment. At five EV intervals, four images can cover a range of 0.7 to 4200000 cd/m^2, and the maximum shutter speed is 1/30, which is very fast. Such sets can be used for measurements in daylight environments because they can be taken in a shorter period of time. Conversely, when measuring indoors or at night, the exposure interval of the image set can be reduced and the number of images can be increased slightly to measure lower luminance.

5. Conclusions

Thus, the use of 14-bit RAW files made it possible to reduce the number of images required while maintaining photometric accuracy, thereby reducing the time required for the taking of pictures. It was also found that the measurement could be performed more efficiently if a set of images was prepared for each case, such as when measuring a bright space with daylight or when measuring a dark room. The methods used in this study are expected to reduce the effects of weather-related luminance fluctuations and provide more accurate luminance distribution data. However, these methods require script adjustments for each camera owing to differences in RAW file formats, such as the number of bits and black level.

PO169

INTEGRATIVE LIGHTING LUMINAIRE WITH HIGH CCT RANGE AND VERY HIGH CRI

Kobav, M. B.[1], Klinkon, M.[2], Juarez, M.[3], Bizjak, G. [1]
[1] University of Ljubljana, Faculty of electrical engineering, Ljubljana, SLOVENIA, [2] Ledluks d.o.o. Šempeter pri Novi Gorici, SLOVENIA, [3] Seoul Semiconductor Europe GmbH, Munich, GERMANY
matej.kobav@fe.uni-lj.si

Abstract

1. Motivation, specific objective

Integrative lighting (IL) is a lighting system designed to improve human well-being and performance in a lit environment. Lighting design should take into account the needs of the space and its occupants, such as the illuminance required for different activities, the colour temperature of the light, and the effects of lighting on mood and productivity. Therefore integrative lighting fixtures must allow users to adjust the colour temperature and intensity of light output to create different lighting effects and atmospheres. IL integrates both visual and non-visual effects and produces physiological and/or psychological benefits for people. IL can be controlled through a variety of methods, including manual control, programmed settings, and automated systems that use sensors and algorithms to adjust the lighting in response to changes in the environment or user preferences.

The benefits of IL include increased productivity but the focus is on improving well-being. IL is used in a variety of settings, including hospitals, offices, residential buildings, nursing homes and industry. In recent years, IL has evolved with the development of new lighting technologies and control systems.

IL can be realised with tunable white lighting (TWL) which usually uses two types of LEDs, one with the low CCT value (2 700 or 3 000 K) and the second with the high CCT value (6 500 K or more). With a dual-channel driver it is possible to combine luminous fluxes of both LED types to achieve all CCTs between the bordering ones while maintaining the same illuminance. In the CIE xy graph, the bordering two CCTs and all reachable CCTs lie on a straight line, while the Planckian locus has a curved path between two CCTs. Therefore all spectra achieved by only two LEDs with different CCTs have a lack of green colour.

2. Methods

In the developed luminaire three different LEDs are used. Two white LEDs with very high CRI (over 95) and with extreme CCTs of 1 800 K and 15 000 K and one greenish LED with lower CRI and CCT of 4 000 K. After all electrical and spectral data were measured spectral distributions were calculated for approximately 1 MIO combinations of LED's current settings. Beside spectra also CCT, CRI, luminous flux, x and y as well as u' and v' coordinates and Duv were calculated. All combinations where CRI was less than 95 and Duv was less than 0.06 were not considered. With remaining current combinations, it was possible to create 7th degree polynomial functions to drive the three channel driver to achieve spectra between 1 800 K and 15 000 K with CRI above 95.

3. Results

A ceiling luminaire measuring 600 mm x 600 mm was designed with an appropriate number of LEDs. A four-channel DMX/DALI driver was added to the luminaire. In the first stage, 7th degree polynomial functions were calculated using Labview on a personal computer to drive changes in the CCT and luminous flux of the luminaire. The measured values were in line with expectations, and all spectra followed the Planckian locus on the CIE xy diagram. In the

second stage, simplified functions were programmed in Casambi, which was connected to the driver instead of a computer with Labview. With Casambi, the same luminaire can be driven with just two sliders, one for adjusting the CCT from 1 800 K to 15 000 K, and the other for the luminous flux. The functions are defined in a way that the luminous flux remains consistent across the entire range of CCTs and does not change with the CCT adjustment. For all measured spectra, the melanopic daylight efficacy ratio (M-DER) was also calculated. The M-DER range for our luminaire is from 0.28 to 1.4.

4. Conclusions

Our study confirms that it is possible to design an integrative lighting luminaire with a high CCT range and very high CRI using only three types of LEDs. In our case, we were able to cover the range of CCT between 1 800 K and 15 000 K with CRI above 95.

PO171

THE CARBON FOOTPRINT OF LIGHTING RENOVATIONS OVER A TEN-YEAR USAGE PERIOD AT EU REGION

Marjamäki, L.[1], **Juslen, H.[2]**
[1] Helvar Oy Ab, Espoo, FINLAND, [2] Helvar Oy Ab, Espoo, FINLAND
Lotta.marjamaki@helvar.com

Abstract

1. Motivation, specific objective

Climate crisis, fuelled by human activities, is a global threat to human health and environment. There is an increasingly growing need to swiftly curb greenhouse gas emissions to limit global warming to 1.5°C from pre-industrial levels. Reaching the 1.5°C target requires global carbon emissions to be almost halved by 2030, and net-zero emissions to be reached by 2050. Swift cuts to the emissions are needed on governmental, corporate, and building level.

Carbon footprint is a useful measure for comparison of products and solutions, and well-executed studies not only enable product and solution development to reduce emissions but allow for improved system design as well. Indeed, comparing carbon footprint of alternative lighting renovation solutions enables environmentally conscious decision making that considers not only the production of lighting components, but the total lifecycle of the lighting system. But in addition to reducing greenhouse gas emissions of products, solutions and buildings, the carbon footprint is also an important indicator in sustainability reporting under the European Union’s recently adopted Corporate Sustainability Reporting Directive.

The objective of this study is to calculate the carbon footprint of lighting renovation project, measure the impact different factors may have on it, and to determine which solution is the best option for in the investigated scenario.

2. Methods

Since lighting can be executed in different ways, this paper compares basic scenarios which differ in their principles for lighting control. Two fast fit-out retrofit scenarios with selected lighting control strategies are compared: one DALI-wired solution, and one wireless solution. The scope of the study includes raw material acquisition, manufacturing, installation and use of the products. Considerations are also taken for cases where lighting data can be used to decrease carbon footprint of other building solutions. The scenarios are modelled using Life Cycle Assessment methodology, which allows comparisons of complete lifecycles and individual lifecycle stages. There are four steps to Life Cycle Assessment, which are goal and scope definition, forming of lifecycle inventory, lifecycle impact assessment, and interpretation of results. The steps are conducted according to the ISO 14040 and ISO 14044 standard. OpenLCA 1.11.0 software and ecoinvent 3.9.1 LCI-database were used.

3. Results

The main results of the study are the carbon footprints of solutions, extending from extraction of raw materials to production of components to the installation of the new lighting system. The energy saving strategies of the solutions are also studied and their impact on emissions calculated. Study is still on-going, but initial results indicate that some of the substantial contributors to the carbon footprint are the electronic components used in lighting control products and the amount of needed cabling. Electronic components make up most of the product cradle-to-gate footprints, integrated circuits being the most carbon-intensive components. The impact of cables is expected to owe not only to the embodied carbon of new cabling, but to the renovation that may be required.

4. Conclusions

Carbon footprint is recommended to be taken into consideration in lighting renovation planning to ensure the climate efficiency of the solutions. Three things should be considered when choosing between different lighting control solutions: the carbon footprint of the solution, the energy savings generated during solution’s lifetime, and combined impact of both. Indeed, while both carbon footprint and energy savings are both great indicators on their own, the final judgement should consider the whole system during its entire lifetime to ensure that the comparison takes all relevant factors into consideration.

PO176

LIGHTWEIGHTING OF 3D MODELS BASED ON BIM AND WEBGL

Rong, Z.[1], Ping, Y.[2]
[1] Shaanxi University of Science & Technology, Xi'an, CHINA, [2] Shaanxi University of Science & Technology, Xi'an, CHINA
2523292655@qq.com

Abstract

1. Motivation, specific objective

BIM (Building information model) has high application value in the whole life cycle of building design, construction, operation and maintenance. At present, BIM models have problems such as large amount of data and high requirements for computer performance. In addition, if the created BIM model is directly used to display it on the web side, it is easy to lead to problems such as long rendering time, slow model loading, poor user experience, and even terminal stuck. Therefore, it is necessary to lighten the BIM model data and place it on the web side for rendering optimization

2. Methods

In this paper, glTF format is proposed as the data transmission format between Revit and the web, and then the three-dimensional mesh in the glTF format is compressed by redundant vertex deletion method and Draco algorithm, and the proposed LOD optimization algorithm is used to selectively remove and render components in the model scene. Firstly, by designing the content of the Revit secondary development interface, the direct conversion of RVT model source files to glTF format is realized, so that the signal BIM model is no longer limited by professional software. Secondly, while converting file formats, aiming at the problem of large types of models and large amount of data, this paper studies the internal data, appearance geometry and file compression through redundant vertex deletion method and Draco algorithm. Without affecting the usage effect, the amount of data in the model is greatly reduced. Finally, combined with HTML5 and WebGL technology, the Web-3D model display function module is developed, which realizes the lightweight display of signal BIM model and user interactive operation.

3. Results

Through example verification, this paper successfully completes the lightweight visualization application of signal BIM model based on glTF format and WebGL technology, and uses LOD optimization algorithm to optimize rendering to reduce GPU load and further improve loading rate and rendering efficiency.

4. Conclusions

This paper selects glTF format, which is very suitable for loading and rendering on the web side, as the target data format. By designing the content of the Revit secondary development interface, the direct conversion of RVT model source files to glTF format is realized, so that the signal BIM model is no longer limited by professional software.

At the same time of file format conversion, aiming at the problem of large types of models and large amount of data, this paper studies the internal data, appearance geometry and file compression. Without affecting the usage effect, the amount of data in the model is greatly reduced.

Combined with HTML5 and WebGL technology, the Web-3D model display function module was developed, which realized the lightweight display of signal BIM model and user interaction operation.

Through case verification, this paper successfully completes the lightweight visualization application of signal BIM model based on glTF format and WebGL technology.

PO01

ACCURATE MEASUREMENT OF DRIVERS' REACTION TIMES IN THREE DIFFERENT ROAD LIGHTING SETTINGS

Nilsson Tengelin, M.[1], Källberg, S.[1], Lindgren, M[1], Ebenhag, S-C.[1]
[1] Department of Measurement Science and Technology, RISE Research Institutes of Sweden, Borås, SWEDEN
Maria.Nilssontengelin@ri.se

Abstract

1. Motivation, specific objective

Modulated light is one of the best ways to attract attention and is therefore used in various warning systems and alarm signals, e.g., on emergency vehicles and at railway crossings. Humans are most sensitive to modulation with a frequency of 8-10 Hz but consciously notice direct flicker up to about 90 Hz. Modulation of light at frequencies above the critical threshold are not directly perceived but can be noticed in stroboscopic effects. Some individuals are very sensitive to modulated lighting, while others are not at all sensitive.

Modulation do not consciously attract our attention if they vary faster than the eye can perceive, but studies have shown that such signals nevertheless influence our alertness and attention. Modulated light can, even though it is not consciously detected by the eye, still be registered by receptors in the retina, sent on via the optic nerve to the brain and subliminally influence the individual's behaviour.

Research indicates that modulated lighting can produce short-term positive effects in the form of shorter reaction time and increased alertness. If it can be demonstrated that these effects also occur in an outdoor environment, there are possible applications in traffic situations where there is an increased risk of accidents, such as complicated intersections or roundabouts, tunnels, and pedestrian/bicycle crossings. Investigations of these effects in outdoor modulated lighting at frequencies above the critical threshold have not, to our knowledge, been carried out before.

Thus, there is an objective to investigate whether new technology for lighting of roads at critical conflict points can be used to increase the attention of road users and thereby increase traffic safety during the dark hours of the day. A faster detection of risks and a shorter reaction time would lead to fewer and less serious traffic accidents.

Another objective is to investigate how a driver's reaction time is affected by the light level on roads. To balance energy consumption, light pollution, and traffic safety there is a need to evaluate which effect the level of illuminance on the road and its shoulders has on traffic safety.

2. Methods

The experiment was carried out in the field with drivers in a realistic traffic environment at a state-of-the-art test track. Modified road lighting was set up where the output of the lamps was temporally synchronized.

Three different lighting settings were used:

1. Constant output – 25 lux horizontally at road surface.
2. Modulated output (90 Hz) – 25 lux horizontally at road surface.
3. Constant output – 10 lux horizontally at road surface.

Test drivers, persons with a valid driver's licence, were recruited and invited to the test track. Hidden targets, designed to suddenly appear on the side of the road by a fast-turning

mechanism, were placed along the track with the intention to trigger a response of the test driver. The drivers were instructed to brake as quickly as possible when a target appeared. The reaction time was the elapsed time from when a target became visible until the driver reacted.

A target appeared when a laser beam across the road was disrupted by the moving car. There was a total of four targets along the track and the activation of the targets was controlled by arming them remotely according to a pre-determined test protocol.

Over three evenings, a total of 40 research subjects completed the test. The subjects were in of the ages between 23-73 years, 27 of them males and 13 were females. Each driver completed 12 test rounds where the lighting setting and which target would appear was altered between each round. The schedules were randomized between the drivers.

The brake and gas pedals were modified with pressure sensors and every applied or released pedal pressure was registered and time stamped using GPS-time. The pedal events were then compared with time stamps of each appearance of the targets. Thus, the reaction time from appearance of a target to release of gas pedal and the time to put the foot on the brake pedal was measured.

Before the test, the drivers assessed their sleepiness and reported their driving experience and habits. After the test, the drivers were again assessing their sleepiness and asked to give a self-rated experience of the traffic situations and lighting settings.

3. Results

All test drivers followed the instructions and managed to observe and react to the targets on most occasions. Bad weather conditions on one of the test events caused problems with the targets, causing some missing data. Reliable time stamps for the brake pedal were recorded for almost all drivers and events, while quite a few time stamps were missing for the gas pedal. The reaction times were generally consistent for each driver but with significant individual variations. Overall, the differences in reaction time between the three lighting scenarios were small.

Most test drivers did not notice the difference between the different lighting settings even though there was a difference in the illuminance level on the road by a factor of 2.5 between the high and low intensity setting.

4. Conclusions

In this study we have demonstrated a novel method to measure driver reaction times with high accuracy with the aim of investigating the influence of road lighting on the attention of a test driver. This study adds information to the research on how people are affected by modulated light. If lighting modulated above the critical threshold can increase the attention of road users (car drivers, pedestrians, and cyclists) it could be used to increase safety in critical conflict points. As longer exposure to modulated light has been shown to have negative effects on people, the use in traffic situations would be limited to short exposures at selected areas.

Furthermore, road lighting with intelligent control can be used to adapt and optimize the amount of light to road surfaces with different brightness (wet and dry asphalt or snow respectively) for energy savings and reduced glare risks. However, for this to be applied thorough investigations of the light level influence of the reaction time is needed.

PO04

A POWER-EFFICIENT SMART LASER-PHOTOLUMINESCENT-LIGHT (LPL) WITH PV-SYSTEM INTEGRATION: EXPERIMENTAL ANALYSIS AND OPTIMIZATION FOR PEDESTRIAN ROADS

Belloni, E.[1], **Celli, I.**[1], Cotana, F.[1], Nakamura, S.[2], Pisello, A.L.[1], Villacci, D.[3]
[1] Department of Engineering, University of Perugia, Perugia, ITALY, [2] Department of Electrical and Computer Engineering, Solid State Lighting and Energy Electronics Center, University of California Santa Barbara, CA, USA, [3] Department of Industrial Engineering, University of Napoli "Federico II", Napoli, ITALY
elisa.belloni@unipg.it

Abstract

1. Motivation, specific objective

The future is oriented toward massive urbanization growth due to the increasing number of people living on the Earth. According to data analysis, 68% of the worldwide population is expected to live in urban areas within 2050. Smart cities allow the development of an interconnected, adaptive, and innovative system that can lead to efficient energy use, better resource management, the emissions reduction, and a much more sustainable economy.

Lighting demand in built environments corresponds to almost 14% of the global energy use, with great potential for energy saving thanks to innovative solutions and combination of passive-active strategies. The use of LEDs instead of traditional systems decreased the electricity consumption in Public Lighting Systems (PLSs) up to 50% maintaining the same levels of illumination. Nevertheless, periodic maintenance and environmental conditions of LED luminaries impact on the operation costs and great attention should be also considered to the quality aspects such as the lighting scattering, the uniformity, and the glare. In PLSs fields the concepts of smart electrified environments are growing up: the implementation of IoT, the use of artificial intelligence for the scheduling of the ON-OFF periods and the integration of transactive energy technologies, renewable energies sources, and energy storage systems can further improve the technical and economic operations of the systems.

In this context, the present paper focuses on the development of an innovative next-generation smart lighting device based on combining a 445 - nm blue diode laser and photoluminescent pavements, to achieve a self-lighting surface for future outdoor applications. The combined technology, called LPL (Laser Photoluminescent Light), can lead to consistent energy savings thanks to very low energy consumptions of the laser scanner and the short ON periods of the lamp. The system can be scheduled thanks to a managing software: the variable opening angle, the length of the beam, and the scanning frequency can be dynamically controlled. Photons produced by laser light are absorbed by photoluminescent pigments placed in the pavement and then gradually released in the form of light. Several kinds of photoluminescent pavements were examined and both the electricity consumptions and the lighting performance (illuminances, luminances, uniformity) were monitored in different configurations. Finally, a solar PV panel with integrated battery was used to make the system independent from the public grid.

2. Methods

The laser variable angle scanner prototype was developed by Engineering Department researchers of University of Perugia (Italy) together with an Italian company and it is able to operate through a dedicated management software. The prototype was installed in lab for measuring the illuminance and its decay together with the electricity consumptions. Lighting performances were monitored by considering both photoluminescent tiles and cement-based composite materials mixed with photoluminescent pigments: both the solutions are suitable for pedestrian walkways in typical green areas. Therefore, the principal lighting parameter monitored during charging and discharging phases is the illuminances on both horizontal and vertical planes, considering the minimum limits required by EN ISO 13201.

The photoluminescent pavements were discretized through a grid of points in which illuminance was measured every 5-10 minutes to evaluate the charging trend and the decay transient; the same procedure was repeated for multiple operating parameters profiles in order to find the best configuration able to obtain adequate lighting conditions with the minimum electricity consumptions.

The experimental campaigns were carried out also outside and with a PV-panel with integrated battery used for the electricity supply of the lamp. The annual energy consumption indicator was calculated on the basis of ON-OFF periods profiles.

Finally, a preliminary visual comfort analysis was performed by means of questionnaires and glaring measurements.

3. Results

The energy consumption associated with each operating profile was evaluated through the Annual Energy Consumption Indicator (AECI), whereas the lighting performances were analysed through mean illuminance values. The uniformity calculated is more than 90% and the glaring index was also evaluated. The illuminance required for pedestrian roads can be reached on the photoluminescent tiles pavement in about 5-10 minutes and the decay period is about 35-40 minutes: the lamp can be maintained switched ON for only 10-20% of the total darkness period.

Results were compared with other conventional LED solutions applied for the public lighting of green and pedestrian areas. Considering the same operating time, the LPL solution combined with photoluminescent tiles is able to allow a consistent energy saving (up to 70% without the implementation of a solar panel and accumulation battery system). Nevertheless, the performance obtained on the cement-based pavement with photoluminescent pigments are worst: the illuminances reached on the surface are low and the electricity energy consumptions are comparable to those of a LED standard solution. As concerning the preliminary visual comfort analysis, it was observed that for 60% of the interviews the environment is neutral or bright and for 30% it is slightly dark. Anyway, for almost 80% of the respondents the environment is comfortable or neutral as concerning the visual sensation.

4. Conclusions

Glass tiles with integrated photoluminescent doping and photoluminescent paintings are already installed for directional visibility issues in walking pavements for pedestrians. They are also used for vehicle accessible streets, biking paths and pedestrian routes. Nevertheless, their large-scale implementation is facing issues related to their long-term performance, which still does not meet the economic sustainability potential. That is the reason why in the present paper an innovative lighting system is proposed for fast and efficiency charging those materials able to re-emit light when better needed.

Experimental results show the promising performance of the LPL system: low electrical consumptions and uniform distribution of the illuminance can be easily reached by the innovative laser lamp coupled with photoluminescent tiles. The preliminary visual comfort analysis shows that the final light emitted by the pavement is considered neutral/comfortable for the walkers even if the blue component is prevalent. The addition of a PV panel with storage can make the lamp independent from the grid, especially in spring-summer periods.

PO08

DAYLIGHTING UNDER SKY CONDITIONS IN AN URBAN AREA

Cruz, R. Y.[1], Guadarrama, G. C.[1], Marambio, A. E.[1]
[1] Faculty of Architecture, National Autonomous University of Mexico, Mexico City, MEXICO
raquelyerani@comunidad.unam.mx

The correct use of daylighting will depend on the study of the natural and urban conditions of a region. One of the main variables that determine the availability of natural light in a site is cloudiness, since under each different type of sky condition its dynamics will be different, identifying the frequency of this phenomenon and the predominant sky type on a site, it is possible to generate better strategies for the use of sunlight as a lighting resource.

This research focused on the study of the natural environment, climate elements that condition daylight on a site and its relationship with the existing urban environment of the Basin of Mexico.

The main variable that conditions this availability was studied, characterizing the different types of sky that occur in the Basin in their basic classification of overcast, partly cloudy and clear sky (CIE, IES) and from them generate strategies in the urban environment, since the characteristics and dinamic of natural lighting outdoors will determine the final lighting availability indoors.

The methodology used for this characterization was divided into three important sources of information: on the one hand, the data generated in synoptic observatories carried out by a professional throughout the day of sky conditions was gathered, on the other hand, it was systematized and processed information from a TSI880 Total Sky Imager installed on platforms of the National Autonomous University of Mexico and finally satellite images acquired from the European satellite Sentinel 2 were processed by remote sensing. The 3 sources of information were compared to characterize overcast, partly cloudy and clear sky conditions, yielding coefficients to represent the seasonal and diurnal frequency during a typical meteorological year.

It is important to identify and compare the information obtained and data measured on site to determine the real characteristics of a site, in this investigation it is intended to characterize these cloudiness conditions based on the typical climatic conditions that actually occur in the case study, starting from the study of the natural environment, strategies can be designed in the early stages of architectural and urban design.

The represented frequency was compared with the irradiance and horizontal illuminance variables of the site, which had an important correlation in the behavior of lighting levels with the presence of cloudiness. The validation criteria were made up of the comparison of the data from each of the sources and with their dependent variables that translate into the lighting levels measured at the same site.

The results of each one of them yielded different cloud cover coefficients, but within the range that characterizes each sky condition, therefore, satellite image processing could be used to determine and know the predominant sky conditions and lighting dynamic of a site, since frequent synoptic observations are not always available in some cities and rural areas and there are very few daylight observation platforms with specialized equipment. The ratio and margin of error between each measurement was less than 5%, so remote sensing and its processing could be trusted to characterize such cloud conditions in a region.

The visualization of *cloud maps*, in addition to their processing images to obtain numerical data, is also important to know the distribution of cloud cover in a region, together with other urban variables represented in maps such as population and housing density, green areas, crowded areas or land uses, specific strategies can be generated according to the climatic and physical conditions of the cities.

Knowing the frequency of cloud cover throughout the day and throughout the year will help us to know the dynamics and quality of natural lighting in a region and its main element, whether it is direct or diffuse lighting, which should be taken advantage of. In a different way, these investigations help us to better understand cities in order to take better advantage of natural features and generate key strategies in their planning and design. This research is a starting point for further studies on the illuminance of the sky dome and apply the corresponding mathematical models for CIE standard skies, it is important to know the real conditions initially before generating software simulations.

PO13

USING A CASE-CONTROL METHOD TO EXPLORE THE IMPACT OF LIGHTING ON CYCLE RATES: INVESTIGATING THE CHOICE OF CASE AND CONTROL TIME PERIODS

Balela, M.[1], Uttley, J.[1], Fotios, S.[1], Yesiltepe, D.[1]
[1]School of Architecture, University of Sheffield, Sheffield, UK
mbalela1@sheffield.ac.uk

Abstract

1. Introduction

Several studies have used variation in ambient light level (i.e. the change from daylight to darkness) as a natural intervention to investigate the outcome of change in light level on outdoor events such as road traffic collisions, crime, and traffic flow.

An intention of these studies is to capture the effect of different ambient light levels but for events occurring at the same time of day. One approach for doing this is to consider seasonal variation of daylight over the whole year, picking a time window in the morning or evening which is in daylight for one part of the year but in darkness for the other part. This period of daylight and darkness at different times of the year is the *Case hour*. (While the time period might be more precisely set, we use here an hour because that is the interval at which the data we analysed are reported). In the northern hemisphere, the case hour is likely to be in daylight for the months of April to August and in darkness for the months October to February. The remaining months are those in which the case hour is in civil twilight for at least some part, and this is omitted to avoid ambiguity. Other than light level, there are other changes between these periods that may influence the behaviour of interest, such as changes in weather. To account for these other changes, data in case hours are compared alongside control hours using an Odds Ratio (OR). *Control hours* are those in which the ambient light level remained in daylight (or remained in darkness) across the same period for which the case hour transitioned from daylight to darkness.

The availability of case and control hours at a location depends on the seasonal variation of daylight and darkness and hence by latitude. For example, in Trondheim, Norway (latitude 63°25'49.76"N) the case hours can extend for ten hours, from 4:00 to 7:59 (morning) and 17:00 to 22:59 (evening), and the control hour can extend for three hours in daylight (11:00 to 13:59): there are no control hours in darkness because civil twilight persists through the night for some days in June and July. In Arlington, VA, USA (38°52'51.64"N) the case hours extend for three hours, from 06:00 to 06:59 (morning) and 18:00 to 19:59 (evening), while the control hours extend for eight hours in daylight (8:00 to 15:59) and seven hours in darkness (21:00 to 04:59).

Typically, previous studies used just one case hour and one control hour. Given that other options are available, it is worthwhile to question whether the conclusions drawn are robust to different choices.

In the current work we investigate the extent to which the choice of case and control hours matter. To do that we focus on analysis of cyclist flows. Previous studies (Table 1) found that, for a specific time of day, there were fewer cyclists after dark, revealed by an OR significantly greater than 1.0. In the current analysis we compare the ORs obtained for different combinations of case hours and control hours to determine the extent to which this choice affects the odds ratio.

2. Methods

The data used for these analyses were cyclist flows recorded in cities using automated counters. Several locations are being investigated: at this point we report analysis from one city, Birmingham, UK (52°28'53.11"N), which was the focus of a previous study

The data are reported at hourly intervals. For Birmingham there are 49 counters and we used data for the period from 1/1/2012 to 31/12/2015 to follow previous work. The analyses used all permitted combinations of evening case hours and daylight and dark control hours. Case hours were those where the hour was daylight and darkness for some part of the year: control hours were those where it was either daylight or darkness for the whole of the year. Periods of civil twilight were excluded. For Birmingham, this resulted in four case hours (from 17:00 to 20:59) and 10 control hours (daylight 09:00 to 14:59; darkness 23:00 to 02:59).

3. Results

The ORs ranged from 1.26 to 2.62 where an OR>1.0 indicates a reduction in cycling numbers after dark. For all combinations of case and control hour, the OR indicated a statistically significant effect, and also an effect that was at least of a small effect size. The data shows some interesting trends: for example, dark control hours led to higher ORs (mean 2.01) than daylight control hours (mean 1.65), and later case hours led to higher ORs than did earlier case hours (17:00-17:59, mean = 1.47; 20:00 to 20:59, mean = 2.18). the variation appears to be systematic with time of day.

That means the conclusion reported in previous analysis of Birmingham (OR=1.32) was credible in terms of accuracy (a significant reduction in cycling after dark) but cross comparison with other locations would require consistent choices of case and control hours.

In ongoing work further locations are being analysed. Given that there is some variation, a means of expressing this is required. For example, this might be a mean weighted by the numbers of cyclists in each combination of case and control hours, or reporting the average and some measure of range, such as the lowest and highest values found.

PO14

DARKNESS IS A GREATER DETERRENT TO CYCLING IN SUBURBAN THAN IN CITY CENTRE LOCATIONS

Yesiltepe, D.[1], Fotios, S.[1], Uttley, J.[1], Balela, M.[1]
[1] School of Architecture, University of Sheffield, Sheffield, UK
d.yesiltepe@sheffield.ac.uk

Abstract

1. Motivation

The installation of road lighting assumes it will support the needs of road users, and in minor/subsidiary roads the primary users are often stated to be cyclists and pedestrians. This work focuses on cyclists: road lighting benefits cyclists by enhancing after dark their visibility to other road users, and by enhancing the visibility of those objects that cyclists desire to see. The operation of road lighting after dark can bring unwanted consequences, such as obtrusive light which reduces visibility of the night sky and harmful effects on the natural environment. Road lighting should be used, therefore, only when the costs and benefits are optimised, defined by one national organisation as "*the provision of the right light, at the right time, in the right place, controlled by the right system*". In this article we suggest that there is a spatial variation in the degree to which road lighting supports cycling, which would in-turn inform the "*right place*" aspect of good lighting.

Previous studies have shown that cyclist numbers are reduced after dark, even after accounting for time of day and seasonal variations. Those studies have made use of the data from automated counters, which report cyclist numbers at (typically) hourly intervals. Data are compared using an odds ratio (OR) for case and control hours. The case hour is an evening hour which is in daylight for part of the year and in darkness for another part due either to seasonal variation in solar altitude or to the rapid change before and after the biannual daylight savings clock changes. The control hour is one which remains in daylight (or darkness) across the case hour transition from daylight to darkness. An OR which departs significantly from 1.0 shows that cyclists numbers have reduced in darkness compared with daylight for the same time of day.

The findings in previous studies show variation in the ORs, both between different cities and between counter locations in the same city. Providing an explanation for this variation would help to be certain about the effect of light. Here we focus on variations within a city. Specifically, we examined an observation that ORs were lower in the city centre and higher in surrounding areas, meaning that the onset of darkness was a greater deterrent to cycling in areas outside of the city centre. There are several reasons why this might be the case. First, that lighting design guidance sets higher light levels for areas of a higher environmental zone (e.g. E4 in urban areas and E3 in suburban areas) and this increase in illuminance is sufficient to reduce the deterrence of darkness to some cyclists. Second, that there are more cyclists in the city centre than surrounding areas, and this greater number of others mitigates the deterrence of darkness, a "safety in numbers" effect. Third, that city centre cycle counters located in the city centre are more likely to capture commuting trips than are those located in peripheral areas, and such destination trips (rather than leisure trips) may be less influenced by darkness – they have to travel to and from work, and usually at the same time of day throughout the year. Finally, this change may be related with the availability of infrastructure for cyclists, with an expectation of more cycling facilities in city centres than in surrounding areas.

2. Methods

ORs were determined for 26 counter locations in Berlin, over the four-year period 2016 to 2019, using a case hour of 19:00-19:59 and a control hour of 14:00-14:59. An OR was calculated for each year for each counter. Overall, this included 7 347 139 cyclist counts. The location of each counter was supplied with the counter dataset, and using latitude and

longitude, the location of each was geocoded in ArcMap. The centre of Berlin city centre was defined using the place mark in Yandex map. The linear distance between the city centre and each counter was determined using Point Distance analysis in ArcMap. For each year of data, and overall, a scatterplot was created to see the relationship between the ORs and their linear distance from the centre of Berlin.

3. Results

Across all years and locations the analysis suggested a significant reduction in cyclist numbers after dark (OR=1,23, p<0,0001). The ORs were above 1.0 for each of the 92 permutations of counter location and year except for only one. This suggests a spatially and temporally consistent effect that darkness reduces the number of cyclists.

The scatter plots exhibited the expected trend, with higher ORs for those locations furthest from the city centre. These data were modelled using linear best fit lines. The results show a significant positive relationship between ORs and distance from the centre: for the four years of data that were analysed these were in 2016, R^2=0,72, p=0,0001, in 2017 R^2=0,44, p=0,0002, in 2018 R^2=0,34, p=0,0017, and in 2019 R^2 =0,33, p=0,0022.

4. Conclusion

The results of this analysis of 26 counter locations in Berlin show that the deterrence of darkness on cycling increases with distance from the city centre. A counter measure to this would be to increase the brightness of lighting in peripheral areas. In on-going work this analysis is being repeated for cyclist and pedestrian counters in other countries and cities.

PO15

PUBLIC LIGHTING IN PERIODS OF ENERGY CRISIS AND OTHER UNUSUAL SITUATIONS

Gasparovsky, D.[1], Novák, T.[2]
[1] Slovak University of Technology, Bratislava, SLOVAKIA, [2] VSB - Technical University of Ostrava, Ostrava, CZECH REPUBLIC
dionyz.gasparovsky@stuba.sk

Abstract

Recent couple of years the changes in geopolitical situation and abundance of natural disasters due to global phenomena in consequence of climate change lead to unability to provide lighting as necessary. The more it concerns public lighting afforded by local or state authorities – road and urban lighting, floodlighting and architectural lighting, lighting in schools and offices etc. Armed conflicts, earthquakes, tsunami etc. directly affect the impacted area but consequences indireclty go far beyond, up to a global level. Range of the negative impacts is broad: from insufficient supply of energy and lack of financial budgets, through damage to technical means up to the failure of critical infrastructure.

Lighting belongs to the system of public services provided to support personal and traffic safety, to facilitate orientation and perception of the environment, to aid in creating heathful environment and in peaceful times also for beautification and aesthetical enhancement of illuminated objects or public spaces. Safety role of lighting has key significance amongst all functions. Although there are no reliable data available for extreme and sudden deterioration of situation in large-scale magnitude, according to the medialized information, after blackout of road lighting in the capital city of Ukraine Kiïv, the crash rate increased six times. This is an unprecedent figure even without proper analysis of boundary conditions. In case of pure economic constraints we are also witnessing unrivalled measures of municipalities and other local, regional or state-level authorities tending to switch off or reduce lighting, neglecting the consequences.

It is obvious that such unusual situations can occur although it is not desired. From impaired vision up to the full loss of the function these should, however, impose response in terms of adequate counter-measures, e.g. traffic speed limitation, ban of certain vehicles and curfew recommendations in road lighting, or adapting the building operation time to daylight availability and re-arrangement of workplaces for better harvesting of daylight as examples in interior lighting.

In most of developed countries there are no guidelines for responsible lighting and/or blackout counter-measures in case of long-term emergency, crisis and other unusual temporary situations. This paper aims to analyze various deviated technical, economical and social conditions affecting lighting, to draft a classification scheme with different levels, to outline possible solutions and to suggest further steps and hints for developing guidelines for lighting in critical, extraordinary and other unusual situations, as a self-standing document or as part of e.g. civil defence regulations. Proposals presented in the paper are taking into account consultations with relevant authorities such as the police department, crisis management body, association of municipalities, public health office etc.

PO19

PUBLIC PARTICIPATION GEOGRAPHIC INFORMATION SYSTEM AS A TOOL FOR OUTDOOR LIGHTING STUDIES

Ingi, D.[1], Bhusal, P.[1], Kyttä, M.[1], Pinho, P.[1]
[1] Aalto University, Espoo, FINLAND
dmitrii.ingi@aalto.fi

Abstract

1. Motivation, specific objective

The visual appearance of urban environments significantly impacts citizens' various urban experiences, activity levels, and walking patterns. However, urban planning research and practices predominantly focus on the appearance of cities during the day, and the impact of artificial lighting on the outdoor urban environment after dark needs to be addressed carefully. The development of digital methods, which are used in urban research, such as citizen science, real-time interactive approaches, and participatory mapping through web-based mapping surveys, is gaining momentum day by day. This study aims to explore the possibilities of using the online public participation geographic information system (PPGIS) methodology to study the impact of artificial lighting on various urban experiences, including perceived safety in the outdoor urban environment after dark.

2. Methods

To explore the possibilities of the PPGIS methodology, the case study was conducted at the Aalto University campus area using a citizen engagement platform. The study collected data from 111 participants, who mapped 282 safe and unsafe places through the specially designed web survey. Each selected place contains information on perceived safety and lighting conditions, such as overall lighting quality, perceived brightness, uniformity, colour temperature, colour rendering, and glare. In addition to the data collected from the participants, contextual data about the area, such as highways infrastructure, green zones, buildings, and water layers, as well as street lighting data, were obtained from available open and public resources.

3. Results

This paper investigates various features and considerations to keep in mind when designing a PPGIS survey for outdoor lighting studies. It focuses on the use of web-based surveys to gather information about location-specific human values, perceptions, behaviour, and preferences. The paper discusses different types of questions that can be applied, including mapping questions that use points, lines, polygons, and more traditional survey questions. The paper examines potential challenges that may arise during the survey design process and presents feedback from participants regarding their overall impressions of the survey, its design, and their experiences while taking it. The authors also provide examples of how the data collected from the survey, such as mapping safe and unsafe areas, can be analysed in conjunction with physical environmental factors, such as street lighting and green zone locations.

4. Conclusions

The results suggest that the PPGIS methodology has the potential to be used in future research on perceived safety and other urban experiences, such as perceived restorativeness and aesthetics perceptions after dark. However, some limitations of the approach should be considered and addressed in future research. Overall, the article highlights the importance of evidence-based lighting design solutions in creating safer and liveable urban environments.

PO21

ASSESSING THE USE OF ENVIRONMENTAL LIGHTING ZONES FOR THE PROTECTION OF AQUATIC NATURE CONSERVATION AREAS

Jägerbrand, A.K.[1], Brutemark, A.[2], Andersson, P.[3]
[1] Department of Electronics, Mathematics and Natural Sciences, Faculty of Engineering and Sustainable Development, University of Gävle, Gävle, SWEDEN, [2] Biotopia, Uppsala Municipality, Uppsala, SWEDEN, [3] Calluna AB, Nacka, SWEDEN
annika.jagerbrand@hig.se

Abstract

1. Motivation, specific objective

Using anthropogenic light in the outdoor environment may adversely affect species well-being due to light exposure from spill light that reaches into protected nature conservation areas. The light entering sensitive areas may negatively affect the long-term survival of protected and threatened species in those habitats. Previous studies indicated that specific species groups and ecosystems are particularly susceptible to light emissions and may need extra protection against anthropogenic light emissions. For example, nocturnal species and species with phototaxis, and aquatic ecosystems are considered to be especially vulnerable to exposure to light emissions. However, there are currently no international standards or guidelines that can be used for the protection of nature conservation areas. Despite this, it is of high importance to be able to make recommendations on how to protect conservation areas from the adverse effects of anthropogenic light.

The "*Guide on the limitation of the effects of obtrusive light from outdoor lighting installations*" by the Commission Internationale de l´Eclairage (CIE) differentiates limits for recommended maximum values of light technical parameters by using different environmental lighting zones. The ambient brightness in the environment was originally used as a basis for the differentiation into environmental lighting zones into E0 (intrinsically dark), E1 (dark), E2 (low district brightness), E3 (medium district brightness) and E4 (high district brightness). Therefore, the environmental lighting zones do not consider ecological functions or the need to protect various kinds of nature conservation areas from light pollution. Including ecological considerations would benefit the future development of the environmental lighting zones since it would better protect natural and nature conservation areas from unwanted spill light and light emissions.

There are currently no established methods for determining or choosing environmental lighting zones based on ecological protection in terms of recommended limits for light emissions. In this study wanted to explore whether it is possible to use environmental lighting zones to protect aquatic nature conservation areas. We used geographical information systems (GIS) to combine data from the New World Atlas of Artificial Night Sky Brightness with aquatic Natura 2000 areas and assessed the use of seven and thirteen environmental lighting zones in relevant parts of the Baltic Sea, the North Sea, the Mediterranean Sea, and the Black Sea.

2. Methods

In this study, we wanted to use large-scale geographical data on light emissions and combine it with aquatic nature conservation areas in GIS. We used the New World Atlas of Artificial Night Sky Brightness and downloaded data for the artificial sky brightness. GIS data of aquatic Natura 2000 areas (i.e., aquatic nature conservation areas) was downloaded from the European Environmental Agency geoportal. Because the GIS data only contained Natura 2000 areas for the European Union countries, we had to limit our study areas to include parts of the Baltic Sea, the North Sea, the Mediterranean Sea, and the Black Sea. We divided the artificial sky brightness into seven and thirteen intervals (including zero) and analysed the areas distributed in the different intervals for the total area in the study area and Natura 2000 areas. We assessed whether the various intervals would cover the Natura 2000 areas so that

recommendations could be made for working efficiently with the reduction of light emissions. Case studies exemplified how using environmental lighting zones may aid this process.

3. Results

The results show that there is zero artificial sky brightness in various degrees of the different aquatic Natura 2000 areas, for the Baltic Sea 40%, for the North Sea 44%, for the Mediterranean Sea 21% and for the Black Sea 44%. For the total study area (including Natura 2000 areas), zero artificial sky brightness was 24% for the Baltic Sea, 37% for the North Sea, 45% for the Mediterranean Sea and 64% for the Black Sea.

With increased lighting zone intervals, an increased resolution in areas with different levels of potential light pollution (artificial sky brightness) can be obtained. This can be illustrated using the Baltic Sea as an example, were the highest number of zone intervals show that 0.01% (or 12 km^2) of the Natura 2000 areas are affected by the highest amount of sky brightness. When using the lower number of intervals, the corresponding area affected by the highest amount of sky brightness is 0.05% (or 129 km^2).

The case study from Vasa shows that buildings on terrestrial land (probably greenhouses) may cause unusually high amounts of artificial sky brightness in aquatic Natura 2000 areas. In aquatic areas between Helsinki-Tallinn and Malmö-Copenhagen, high amounts of artificial sky brightness reach into Natura 2000 areas in the surroundings and potentially causes light barriers for the Gulf of Finland and in Øresund.

4. Conclusions

Our preliminary results suggest that relatively high numbers of environmental lighting zone intervals are needed to work most efficiently with mitigation measures since it is easier to identify protected areas with the highest light emissions. Those cases must be investigated to establish where the light comes from and what species are potentially threatened. Nature conservation areas can be exposed to light originating from various sources, e.g., urban areas, large cities, and working places near the sea (e.g., ports). The environmental lighting zone intervals may need to be adapted to national artificial sky brightness (or light pollution) levels. For example, the Baltic Sea experience lower levels of artificial sky brightness than the Mediterranean Sea. Using more than (circa) ten environmental lighting zone intervals will enable officials to work towards light reductions stepwise, focusing first on the most exposed conservation areas. However, using too few environmental lighting zone intervals will require acceptance of relatively high levels of artificial sky brightness (or light emissions) in nature conservation areas unless a strict limit for artificial sky brightness is used.

PO31

MEASURING DARKNESS FOR SAFE AND SUSTAINABLE EXPERIENCES IN NORTHERN CITIES

Pihlajaniemi, H.[1], Vuorenmaa, R.[1], Parhankangas, O.[1]
[1] University of Oulu, Oulu, FINLAND
Henrika.pihlajaniemi@oulu.fi

Abstract

1. Motivation, specific objective

Due to the current energy crisis and need to prevent the worst effects of climate change, short- and long-term strategic changes are needed for many of our accustomed policies of designing urban environments. During the dark, the light in urban and natural environments is produced by electricity, which is in the worst-case fossil based. In the recent years, the amount of illuminated area and light radiation has been growing globally despite the change to LED with aims to save energy. This is understandable since traditionally, many positive values have been related to light and lighting. Lighting supports activities in the environment and enables sight and safe movement. Well-designed lighting has been found to have a positive influence on the feeling of security, and it creates atmospheric and comfortable nocturnal cityscape. On the other hand, some negative influences have also been associated with light: light pollution and interference light affect harmfully people and wildlife. Poorly designed and implemented lighting can be a problem from both a safety and comfort point of view, in addition to energy consumption.

A wider international understanding is emerging that the amount of lighting and the energy consumed must be radically reduced. Several researchers have recently addressed this question from the point of view of their own contexts, presenting preliminary solution models to be explored. These include, for example, creating balance between lighting levels: the amount of light can be reduced while maintaining a positive experience, when contrasts between different parts of the environment are reduced. The dark adaptation process of the human eye can also be taken as one of the design criteria. In general, the view of the great need for lighting during dark has been questioned, and on the contrary, the question has been raised, why minimum lighting intensity levels are defined in the standards, and not maximum levels. The modes of lighting, the scale of lighting and the relationship of the lighting to the urban space and its various users are also important items to consider. Additionally, intelligent lighting that adapts to presence and seasonal conditions such as snow cover offers a technological opportunity for large energy savings and reducing over-illumination.

In this paper, a case study relating to the XXX research project is presented. The general aim of the project is to develop and pilot a new and innovative approach to the planning and implementation of lighting in northern urban environments. The project studies ways to create good and safe experiences of darkness in various urban environments, supporting the well-being of people and nature. The goal is to optimize the use of low illuminance levels with the help of researched design solutions and intelligent lighting control technology. The solutions for well-designed darkness and complementary lighting radically reduce energy consumption in cities and provide tools to change design strategies towards carbon neutrality. By reducing over-illumination, the designed darkness and gloom in the city gives space to the expressions of artistic light – architectural lighting and light art – that support the experience of a safe and comfortable city.

The geographical context of our study in high latitudes in the northern hemisphere is characterized by a long snowy season - up to 5 months. The snow cover creates an environmental, bright white or light-toned element that effectively reflects light and enhances the visual experience of light even when it is scarce. The region is also sparsely populated, with the exception of main urban areas, and nature is a central part of people's immediate environment. The large seasonal variation in natural light conditions means that in the summer the street lights are completely off for about three months, when there is enough light even at night; on the other hand, in the winter season, residents are used to the fact that darkness extends into the active time of the day, when they work, exercise, play, go out and do sports with only electric light illuminating urban environments. The northern regions also have their own cultural relationship with the dark, which is partly connected to people's relationship with nature. Darkness experienced in nature is often associated with positive values: the absence of artificial light gives the opportunity to enjoy the various shades of natural light, dusk and darkness, as well as the northern light phenomena, such as northern lights and the starry sky unsuppressed by light pollution.

The specific aim of this paper within the context of the research project is to present a method of measuring and analysing the visual light appearance in scarcely lit environments in urban contexts and to discuss the premises of designing less-illuminated spaces which would still enable positive experiences of the inhabitants and other users of the city.

2. Methods

As a case study, luminance images are taken with a digital camera and software in the selected dark or over-lit locations in the city of XXX with and without snow cover, and the results are analysed. In addition, lighting calculations combined with lighting renderings are carried out with Dialux Evo program to estimate the effects of either adding lighting or decreasing lighting in a chosen area and the influence of certain design factors such as lighting mode. The case study sites are pedestrian and light-traffic environments.

3. Results

The results of the study help to develop sustainable and energy-efficient solution models and season dependant lighting design strategies for northern urban environments, respecting the values of darkness.

4. Conclusions

In the northern regions with wintertime snow cover, lighting design strategies and processes can be developed to better consider seasonal changes of environmental and visual conditions. Luminance image analyses and lighting calculations are useful tools to understand different shades of darkness, gloom and light for employing them in a more versatile way in the lighting design processes of northern cities.

PO43

COMPARING AFFECTIVE EXPERIENCE OF IN-SITU WALKING BETWEEN DAYTIME AND NIGHTTIME USING WEARABLE BIOSENSORS

Zeng, X.X.[1], Lin,Y.[1], Zhang,B.[1]
[1] Tongji University, Shanghai, CHINA,
linyi_tjcaup@tongji.edu.cn

Abstract

1. Motivation, specific objective

In the field of lighting design, how to evaluate the lighting quality of pedestrian space after dark has been an important topic. The day–dark method mentioned that good lighting is that which minimises the day–dark difference. However, in the relevant applications, the most commonly used method is psychometric scales, which has certain limitation in the accuracy of time and space. The main purpose of this study was to examine the feasibility of using wearable sensors to compare the affective experience of in-situ walk between daytime (Natural Light Scene) and night time (two Artificial Lighting Scenes).

2. Methods

A filed study was conducted on campus walkways to investigate how the different lighting environments influence people's real-time physical and psychological response. A total of 3 lighting scenes were set up for the same campus walkways, which were day scene (cloudy), night scene A (landscape light + street light), night scene B (street light only). A total of 8 college students aged 18-21 were selected to participate in the experiment. A three-channelled multi-bio-sensing devices (EKG, skin conductance, respiration) were used, in addition with a GPS tracker, to measure the in-situ physiological affective responses to environmental stimuli. During each walk, several traditional experiment tasks (i.e.in-depth interviews, psychological Likert scale rating, cognitive map and point-of-interest photography) were conducted in order to capture participants' subjective affective.

3. Results

The results of this qualitative research showed that the bio-sensing approach can help to identify the negative lighting environmental stimuli. Findings revealed certain consistent results between bio-sensing measures combined with spatiotemporal trajectory and traditional methods (i.e. cognitive map and psychological Likert scale rating).

4. Conclusions

These findings revealed that measurement of affective experience with wearable sensors could be a promising method to evaluate pedestrians' responses to different lighting environment and to diagnose negative lighting stimuli. This bio-sensory method can provide evidence to support the improvement of lighting design quality.

PO46

APPLICATION OF NIGHT-TIME LANDSCAPE LIGHTING TO DISASTER PREVENTION

Akizuki Y.[1], Komatsu Y.[1], Yamaguchi H.[2], Nagamachi S.[3]
[1] University of Toyama, Toyama, JAPAN, [2] National Institute for Land and Infrastructure Management, Tsukuba, JAPAN,[3] LEM Design Studio Co. Ltd.
Contact email address: akizuki@edu.u-toyama.ac.jp

Abstract

1.Introduction

Today, night-time landscapes are increasingly being created for the purpose of creating attractions and regional revitalization by taking advantage of local characteristics. A representative example of incorporating night-time scenery into the town development and regional revitalization is Nagato Yumoto Onsen Area in Yamaguchi Prefecture, Japan. A large-scale stairway was created to take advantage of the 18-meter difference in elevation between the parking lot on the highest ground and the centre of the hot spring resort area on the banks of the Otozure River. In conjunction with the creation, a community-integrated night-time landscape lighting design was implemented by S. Nagamachi. Lighting is integrated with low colour temperatures. And automatically dimming control according to three time periods of night-time (17-21:00, 21-24:00, and 24-5:00) achieves both a beautiful and attractive landscape and energy savings.

In this study, we first conducted a survey of the entire night-time landscape lighting area of the area, and examined it from the perspective of a pedestrian space. Then, evaluation experiments were conducted on the large-scale stairway as evacuation routes, and on guiding people from the opposite side of the river to evacuation sites, in order to study the lighting requirements in the event of a disaster.

2. Fact-finding Survey of Lighting Conditions in Nagato Yumoto Onsen Area

The surveys were conducted after sunset on three days in December 2021. The survey was divided into three zones, and 24 measurement points were set up at approximately 30-meter intervals. We measured luminance distribution, vertical illuminance, and floor illuminance from the viewpoint at 24 locations during three time periods. In addition, psychometric evaluation was conducted with 8 subjects for the main direction of the lighting design at all points.

At all locations, floor illuminance decreased as the time of day got later, and with it, the percentage of "visible" rating on the road surface visibility. There were about half of the locations where the "visible" rating did not reach 90% even at floor illumination levels of 1lx or higher, which is the level required by emergency lighting. The road surface was "visible" by many people at an average luminance of 1 cd/m2 or higher. The "ease of grasping the entire space" was evaluated to be fine for most people when the average luminance was 1 cd/m2 or higher, or the vertical illuminance level was 2 lx or higher, which is the illumination level at which a person's face can be distinguished in night-time. The floor illuminance of 1 lx was not sufficient to obtain the "ease of grasping the entire space. The same tendency was seen in the evaluation of "sense of uneasiness," and it can be said that not only the illuminance of the floor surface used as a standard but also the lighting design of the vertical plane is important to improve the psychological evaluation of the night-time landscape.

3. Experiment of Lighting Requirements for Outdoor Stairway

The large-scale stairway was used to study lighting requirements during upward evacuation. The experiment was conducted after sunset on 10/10/2022. Ten lighting patterns were set up for this study. The items measured were luminance distribution, as well as psychological evaluation while 12 subjects moved up and down stairs. In addition to the average luminance of the entire field of view, the luminance distribution image was divided into three areas: "stair surface," "vertical plane," and "sky," and the average luminance of each was calculated.

As the results, the average luminance of 2 cd/m2 on the stair surface is considered necessary to ensure safety during evacuation to higher ground. The " sense of uneasiness " was highly correlated with the average luminance of the entire field of view, with 80% of the respondents reporting "no problem" at 1.5 cd/m2. It can be said that vertical illumination to create an attractive night-time landscape is effective in eliminating a sense of uneasiness, especially when brightness cannot be secured.

4. Experiment of Lighting Requirements for Guiding to Evacuation Areas

In areas along rivers, it may be difficult to reach evacuation areas on higher ground without crossing the river. At night, it is difficult to know the water level, which may lead to a delay in evacuation. Therefore, we examined lighting requirements to guide people to evacuation areas on higher ground on the other side of the river. In the experiment, a total of 15 lighting patterns were set up, including a pattern that emphasizes the stairway, which is the main evacuation route to the evacuation area on high ground, and a pattern that continuously illuminates the plaza and bridge in front of the stairway. The luminance distribution was measured from a point on the opposite shore looking toward the evacuation area, and psychological evaluation was conducted by 13 subjects at the same point. In addition to the average luminance of the field of view excluding the moon, the luminance distribution was divided into two areas: the road surface of the evacuation route and other areas including the vertical plane.

A higher percentage of respondents reported that the route was "recognizable" when the entire route was illuminated than when the stair route was partially illuminated. The same tendency was observed in the "ease of grasping the entire space" and the " sense of uneasiness " reduction. In terms of lighting for guiding people to evacuation routes, continuity from the evacuation point is important.

5. Conclusions

This study examined the lighting requirements for night-time evacuation routes in disaster, based on a measured survey and psychometric evaluation of the current lighting conditions using the night-time landscape lighting system at Nagato Yumoto Onsen.

As the results, it was found that the standards for emergency lighting in buildings may not satisfy outdoor visibility of evacuation road surfaces, that an average luminance of 2 cd/m2 is necessary to ensure visibility of stair surfaces and vertical movement in outdoor stairs, that illumination of vertical surfaces can eliminate a sense of uneasiness, and that continuity from the evacuation point to the evacuation area is more important than partial illumination of the evacuation route.

PO51

A PROPOSAL OF EXTENSION OF DYNAMIC ADAPTIVE ROAD LIGHTING CONCEPT THROUGH A REAL CASE STUDY

Di Lecce, P. [1], Giansante, S. [2]., Baenziger, T. [3]
[1] Revetec srl, Castelnovo né Monti, ITALY, [2] Revetec srl, Castelnovo né Monti, ITALY, [3] EE Consulting, Zurich, SWITZERLAND
paolo.dilecce@revetec.it

Abstract

1. Motivation, specific objective

This paper shows the measured energy saving results obtained by the adoption of a new algorithm to the Dynamic Adaptive Road Lighting (ARL).

The EN 13201-1: 2015 standard and the CIE TR 115: 2010 recommendations have introduced specific chapters on new approaches relating to Adaptive Road Lighting (ARL). The Italian standard UNI 11248 – which is the EN 13201 -1 adapted to Italian needs- defines a series of parameters (speed of reduction of the luminous flux, maximum dimming levels, number and frequency of sampling of environmental parameters, calculation parameters, control strategies, etc.), to guarantee, in various situations, measured in real time, maximum safety and security for the road users.

The Italian standard introduces two adaptive lighting strategies: TAI (Traffic Adaptive Installation), in which only the traffic density is measured and FAI (Full Adaptive Installation), where weather conditions and the luminance of the road surface are also measured. When FAI is implemented and safety conditions are guaranteed, UNI 11248 allows to dim up to 3 lighting categories, often corresponding to the 75% reduction of the luminous flux and energy consumption.

2. Methods

Methods used in this case study include the algorithm defined in Italian standard UNI11248, the risk analysis requested to the Lighting Designers and a new formula to extend the dimming calculation on site to other correlated roads.

In Italy today Adaptive (Dynamic) Road Lighting becomes more and more used, because of the high energy saving and CO_2 reductions it generates: UNI 11431 Italian standard states that the installation of a FAI system could generate, if compared to all night full lighting, an energy saving of more than 50% in most of the cases. One of the reasons why Lighting Designers are encouraged to specify ARL is because the measurements necessary in order to run a FAI installation can be obtained by a LTM (Luminance and Traffic Meter), a very simple device to install and manage.

In Italy LTMs are connected directly to the Gateways and send dimming commands every minute, taking into account the luminance, traffic flow and weather conditions and deciding continuously the dimming level to be adopted according to UNI 11248 standard.

Even if LTM is not so expensive, to have a reasonable 3 years payback it is necessary to install it only on the roads where measurements are valuable, for example in main roads, therefore leaving the secondary road without real-time dimming control.

UNI11248, in these cases, gives the Lighting Designer the possibility to perform a risk analysis and to decide whether the same dimming can be used for other than the main road, therefore extending the use of dimming to other streets and luminaires.

In this case study a specific algorithm was designed in order to extend the dimming possibilities in real time, rather than using a fixed dimming pattern.

3. Results

Instead of simply repeating the dimming level to other groups of lamps, in Agrate Brianza a different approach was designed, tested, and implemented, that is to use data and a specific algorithm from different LTMs.

Agrate Brianza is a municipality of about 20000 habitants, just in the proximity of Milan, in the North of Italy. The area under control is very complex because:

It is so close to Milan and it is crossed by the most congested highway in Italy (A4); Agrate has a number of entering and crossing roads directly influenced by the motorway traffic

It is a small municipality but with a large area, therefore there are zone with very low traffic flow

The North of Italy is an area where frequently fog is present in fall and winter periods

The project starts from a relamping of 3000 LED luminaires, powered by 36 distribution boards.

For each luminaire, a radio frequency control node Zhaga socket, and relevant gateways were installed within the distribution boards.

In order then to enable the use of Adaptive Road Lighting as FAI installation, 6 LTM sensors (measuring traffic weather conditions and luminance of the road surface) were installed, in order to obtain the dimming value to be imposed on the system on which the sensor insists.

In addition, the values measured by the LTM are sent back to a server software and fed to an algorithm to generate new values to be applied on other installations equipped with point-to-point control systems, but without LTM sensor, respecting latency times in accordance with the type of system proposed.

The server is always online and can generate in real time the value to be sent to the gateways, to apply a new control command.

Therefore, only 6 LTM measurements were used to control different levels of dimming of 36 Gateways and 36 groups. Each group was divided as well in sub-groups, depending on the type of road controlled.

It was therefore possible to exploit the full potential of the system by applying Dynamic ARL on 100% of the controlled luminaires. This results in a greater adaptability of the system rather than time-based control profiles, as well as greater energy savings comparable to those described above, and the energy savings potential for all the lighting installations of the Municipality of Agrate could raise up to more than 50%.

4. Conclusions

The algorithm used to determine the lighting levels of ARL was written by including parameters defined by the lighting designer, based on a careful analysis of the roads on which this generated value will be applied and not directly measured.

The challenge of Carbon Neutrality is daunting, and the use of efficient systems is the way forward to achieve the result.

PO53

MEASURING PEDESTRIAN REASSURANCE: COMPARING EVALUATIONS GIVEN BY SOLO PEDESTRIANS AND ACCOMPANIED GROUPS

Gorjimahlabani, S.[1], Mao, Y.[1], Fotios, S.[1], Uttley, J.[1]
[1] University of Sheffield, Sheffield, UK.
steve.fotios@sheffield.ac.uk

Abstract

1. Motivation, specific objective

Reassurance is the confidence a pedestrian might gain from road lighting (and other factors) to walk along a footpath or road: for road lighting the definition in CIE 236:2019 refers in particular to walking alone after dark. A higher level of reassurance is associated with more walking and thus using road lighting to enhance reassurance would be expected to result in more walking after dark.

A common procedure in previous field studies of lighting and pedestrian reassurance is to instruct test participants to visit one or more locations, and at each location describe their feeling of reassurance using one or more category rating items. While the results of previous studies tend to show that higher light levels are associated with feelings of greater safety the findings do not yet reach consensus as to optimal lighting for reassurance. There is a need to better understand the factors which influence the evaluation.

One factor is whether the evaluator provided their analysis whilst alone or with others. This can be broken down into two elements – the number of test participants in a group and the presence of an experimenter.

Regarding group size, while in some studies (Blöbaum and Hunecke; Portnov et al) the participants visited each location alone, resembling the CIE definition of reassurance, in other studies (Boyce et al; Fotios et al) the participants visited locations in groups of around five to ten people. Group size is expected to influence evaluations of reassurance because we tend to feel less safe on our own than when accompanied by others, and the presence of others may also lead to socially desirable responding.

The second element is whether or not the test participant(s) were accompanied by an experimenter. For example, in Portnov et al the test participants were alone, being guided to each location by instructions received beforehand, whereas in Boyce et al the participants were driven as a group to each location by an experimenter. An experimenter may unintentionally infer the purpose of the experiment, or hint at better options or situations, and evidence from Rosenthal shows that an experimenter' awareness of the experiment aims can influence the outcome of subjective evaluations

The influence of participant accompaniment is being tested in an ongoing field study of pedestrian reassurance using the day-dark approach introduced by Boyce et al in which evaluations are conducted both in daylight and after dark. The 140 test participants are allocated into one of two evaluator types, with one type visiting each of the 12 locations in groups of 6 people accompanied by one or more experimenters, and the other type visiting the same locations alone as directed by instructions received beforehand.

PO56

REDUCING STRAY LIGHT IN OUTDOOR LUMINAIRES

Green, B.[1], Kerff B.[2], Dohogne D.[2], Duerr F.[1], Jacobs, V.A. [1]
[1] Vrije Universiteit Brussel, Brussels, BELGIUM, [2] Schréder, Liège, BELGIUM
William.eli.green@vub.be

Abstract

1. Motivation, specific objective

Light pollution is increasing at a rate between 6-10% each year, faster than population growth or GDP increase. We analyse stray light in outdoor LED luminaires using the FRED raytracing software. We demonstrate that Fresnel reflections and dust are the two largest contributors to the light pollution created by a street luminaire, and present methods for eliminating these effects.

2. Methods

Light contributing to pollution is defined in the 2018 French Journal Officiel as light outside the CIE 040:1978 n3 cone, which is a cone of 75.5° out from the optical axis. Upward Light Output Ratio (ULOR) is another common metric for light pollution. Stray light analysis is performed in FRED on outdoor luminaires to determine the mechanisms through which light leaves the n3 cone. These simulations are verified using goniometer measurements.

The concept of ray ancestry is introduced in order to isolate different modes of stray light. Ray filters are applied within the simulation to isolate the contribution of Fresnel reflections. Lumen maintenance factors are used to estimate light scattered due to dust.

The case study of a variety of luminaire lens and protector shapes are compared in order to create rules-of thumb for better Dark Sky Designs.

3. Results

The far field intensity of some selected luminaires is visualized. We examine the contribution of Fresnel reflections to the far field intensity. When light strikes a surface at a large angle of incidence, the reflection coefficient is larger than when light strikes the surface perpendicularly. By plotting rays with Fresnel ancestry > 0, we show that the useful light lost due to Fresnel reflections is larger than what the commonly reported reflection coefficient predicts. Some luminaire shapes result in Fresnel reflections at angles close to horizontal, which is especially damaging in terms of light trespass. Goniometer measurements confirm the presence of this stray light by comparing photometry of a luminaire side-by-side with and without its protector attached.

We show that the amount of ULOR created as a result of dust is up to 20% of the lumen maintenance factor described in CIE 154:2003.

4. Conclusions

When luminaire manufacturers work to reduce light pollution, the exterior protector of the luminaire should be considered as a secondary source of light. This light is created due to Fresnel reflections and scattering. The best design practice for prevention remains to implement a “Full Cutoff” fixture, where no part of the source or protector are visible from viewing angles outside the n3 cone.

In situations where this is not practical, we have presented methods for finding the root cause of stray light in LED based outdoor luminaires.

PO59

ERRORS IN GONIOPHOTOMETRIC CHARACTERISATION OF SURFACES

Iacomussi P.[1], Bernasconi J. [2], Renoux D. [3], Lindgren M.[4]
[1] INRIM, Torino, ITALY, [2] Metas, Bern, SWITZERLAND, [3] LNE, Paris, FRANCE, [4] RISE, Borås, SWEDEN
p.iacomussi@inrim.it

Abstract

1. Motivation, specific objective

The measurement of the spatial distribution of the luminance coefficient, called the *q* coefficient (ratio between the sample luminance – measured in a given observation direction – and the illuminance on the same sample from a given lighting direction) or BRDF (Bidirectional Reflectance Distribution Function), allows an accurate evaluation of the light-to-material interaction. The BRDF is an essential descriptor of material appearance and plays a relevant role in several research fields like digital twins, special visual effects, or industrial and space applications. However, one of the most relevant is road lighting, were partial BRDF is measured for one very grazing angle (1°) and for only lighting angles relevant for the application, measured data are packed in tables called *r*-tables.

Knowing the pavement luminance coefficient, it is possible to design road lighting systems able to provide a given road luminance for the safety of all road users, as stated in European standards (EN 13201 standards family). The setup parameters (spacing and tilting) of the lighting system are calculated using the luminance coefficient of the road and the luminous intensity distribution of the street luminaire. Since the first edition, CIE TR 144 "Road surface and road markings reflection characteristics" provides values of luminance coefficient for several reference road surfaces in relevant lighting directions (*r*-tables). The EMPIR project SURFACE had the task to provide CIE TC4-50 with new metrological knowledge and awareness on road luminance coefficient measurements uncertainty and errors for the CIE TR 144 revision. Usually, *r*-tables are measured on site or in laboratory with specialized goniophotometers (able to provide the angular setup listed in the *r*-tables), at high angular resolution and equipped with a light source and a photometric detector, both with an optical system. Some goniophotometers are optimized for pavement measurements only, while others are more flexible and able to perform full BRDF measurements too.

The paper presents the analysis of the performances of goniophotometers used in road luminance measurements, evaluating the errors introduced by the divergences of the light source and detector optical systems. In the case of road surface measurements, the large dimension of typical samples and the geometrical measurement constraints (lighting and viewing directions) are such that the instrument optical divergence introduces systematic errors, difficult to foresee if the sample BRDF is completely unknown.

2. Methods and results

The metrological performance of a given gonioreflectometer for road surface measurements has been evaluated by modelling the angular resolution and optical performance of the detector and light source optical systems. Then the road surface behaviour was simulated by a parametric model, which entails a diffuse component, a modified Phong component, and an experimentally tailored component to simulate and match different types of pavements. The simulation results are then compared with the measured results on the same gonioreflectometer and pavements to validate the modelling and evaluate the systematic aperture effects errors.

In the end, the effects of the extended size of the optical apertures, combined with the grazing viewing angle of observation (1°) introduce a systematic error that can be greater than 10 % and it is strongly related to the lighting directions (since in *r*-table measurements the viewing direction is fixed) and material reflectance behaviour.

3. Conclusions

The paper describes the impact of divergences of optical systems (of light source and detector) on gonioreflectometer measurements of the luminance coefficient and presents a model for the evaluation of the correlated systematic errors for the specific topic of road surface luminance measurements. The findings can be useful for BRDF measurement uncertainty evaluation too.

PO63

ROAD SURFACE REFLECTION CHARACTERISTICS OF PERMEABLE PAVEMENT USED FOR EXPRESSWAYS IN JAPAN

Miyamoto, K.[1], Fujiwara, D.[1], Hayakawa, M.[1], Maehama, T.[2], Futatsuya, H.[3], Ito, H.[2]
[1] Nippon Expressway Research Institute Co. Ltd., Tokyo, JAPAN, [2] Nexco-East Engineering Co. Ltd., Tokyo, JAPAN, [3] Panasonic Corporation., Osaka, JAPAN
k.miyamoto.ad@ri-nexco.co.jp

Abstract

1. Motivation, specific objective

In Japan, a newly developed permeable pavement has been adopted as the standard pavement on expressways at tunnels and other sections. Conventionally, classC2, which indicates the reflection characteristics of dense asphalt pavement, proposed by CIE, has been applied in designing tunnel lightings. In tunnel lighting facilities using high frequency fluorescent lamps, road surface luminance distributions with a certain level of accuracy can be calculated using classC2. But with tunnels that adopt LEDs, the uniformity of road surface luminance tends to be lower in field measured values compared to calculated values. As the permeable pavement has a higher specularity compared with dense asphalt pavement, the precision of luminance uniformity lowers when calculated using classC2.

For that reason, the reflection characteristics of permeable pavements were examined to secure a certain level of precision in calculating the road surface luminance for designing lighting facilities at permeable-pavement sections of expressways.

2. Methods

A facility to measure the reflection characteristics of road surface was built, taking into account CIE's measurement requirements, and the luminance conversion factor was measured from pieces of pavement collected in Japan. Considering that pavement reflection characteristics change with age, pavement pieces were cut out from sites that have been in service between one to eight years. A piece of pavement made at a factory was also measured as a specimen that has been in service for zero years.

3. Results

The reduced luminance coefficient, obtained by measuring pieces of pavement, was used to create the r-table for each pavement piece. The specular factor S1 of permeable pavement was relatively high in the early years of service and generally equaled classW2. After two years of service, the specular coefficient of permeable pavements lowered as the service years increased, and showed an overall tendency of equaling classC2.

The distribution of road surface luminance measured at an on-site sampling point on a pre-service expressway using permeable pavement and the luminance distribution calculated by simulating the on-site lighting conditions were compared. The luminance distribution calculated using the r-table for an expressway pavement which is zero years in service tended to be overall constant with the road surface luminance distribution measured at the site. The results show that an on-site luminance distribution with a certain degree of accuracy may be calculated using the r-table for the number of years in service which equals that of the sampling site.

The effects of changes in the pavement reflection characteristic, caused by aging, on the uniformity of road surface luminance was studied. Transitions in the luminance uniformity were examined using the luminance uniformity calculated from the r-tables for zero to eight years in the field. The longitudinal uniformity Ul, which affects comfort, slightly changed with age, but there was no noticeable decrease. The overall uniformity Uo, which affects visibility, lowered some 20% after about two years in service and tended to stabilize after that. The

results show that the r-table that matches the age of the pavement should be adopted when designing lightings for expressways where permeable pavement is used.

4. Conclusions

The r-table of permeable pavement created in this paper can generally reproduce the road surface luminance distribution of the site, and the precision of lighting designs for roads with permeable pavement has been improved.

As the overall uniformity of the permeable pavement's road surface reflection characteristics tends to lower with age, lightings may be designed appropriately by considering the aging of pavement and selecting an r-table that match the classification of the lighting designs; that is whether they are for new constructions or for renovations.

PO66

THE ECOLOGICAL SHIFT OF OUTDOOR LIGHTING: TOWARDS A MULTIDISCIPLINARY APPROACH TO DESIGNING ADAPTIVE INFRASTRUCTURES

Pharel, A.[1]
[1] ENGIE Laborelec, Linkebeek, BELGIUM
agathe.pharel@engie.com

Abstract

1. Motivation, specific objective

For the last decades, the outdoor lighting market has been focusing on the energy efficiency of the infrastructures, in a double objective of lowering their operation cost and their carbon footprint. More recently, awareness about the current global biodiversity crisis has been growing and the detrimental impact of artificial light at night (ALAN) on animal and vegetal populations is more and more documented. The understanding of the phenomenon is global and experts from multiple disciplines are nowadays trying to elaborate recommendations and guidance aiming at mitigating the impact of ALAN on biodiversity.

These two movements, reducing energy consumption and reducing biodiversity impact, are sometimes going through the same lighting strategies: extinctions, partial extinctions, dimming strategies, etc. They are nevertheless often contradictory under a technological perspective, less impacting light sources also being the more energy-intensive. At the same time, all of those solutions are bringing-up social issues related to the security of road and street users, their feeling of safety, their comfort. They are challenging social inequalities matters, the nocturnal economy viability and the cities' night-time identities.

Therefore, current refurbishment and new lighting projects have to deal with pressure and demands coming from several directions, with requirements often conflicting with each other. Professionals and expertise now interested in outdoor lighting projects are not historically used to work together and do not share the same approaches, methodologies, narratives, projects timeframes: for instance, sociologists and ecologists long-term inventories of populations are rarely in tune with urban planning practices and infrastructure works.

The need for leading projects with a new approach emerges: methodologies and tools enabling a dialogue between the different expertise are needed to unlock these complex multidisciplinary projects. Additionally, tools easing the relevant stakeholders' engagement – being local authorities, neighbourhood committees, social organisations, etc – are needed to explain, visualise and later implement the co-elaborated solutions.

This analysis slots into a systemic consideration of the humans-environment relationship, which suggests to put aside the partitioned and specialised process of considering human actions. Indeed, considering that human actions have had the global consequences that we know – the current climate and biodiversity crises, for instance –, there is a need for anticipating any snowball effects by carefully assessing the environmental setting in which any new action takes place. That means: to consider human building projects by using systemic and multidisciplinary approaches.

Therefore, the objective of this study has been to define a new framework for addressing complex outdoor lighting projects by finding new narratives, methodologies and tools that can be manipulated by different professionals, stakeholders and expertise, in order to engage them, create a dialogue and allow their close collaboration. The disciplines targeted in this study have been especially ecology, sociology and technical lighting expertise.

2. Methods

In order to define the above-mentioned framework, the study has been broken down into three consecutive steps.

Starting from a lighting expertise point of view – the author's speciality – a theoretical approach has first been used in order to better apprehend the ways of thinking of the other disciplines. This part of the study based itself on a literature review about the impact of lighting on both biodiversity and human beings' security and perception of safety.

Second, a dialogue with different experts of the targeted disciplines has been built, with the aim to precisely define their needs and objectives when addressing such problematics. This second step allowed to elaborate a theoretical methodology that would allow lighting experts, ecologists and sociologists to collaboratively address complex outdoor lighting projects.

A third part of the study intended to challenge the previously elaborated theoretical methodology and to evaluate the need for dedicated tools enabling the practical implementation of the multidisciplinary approach. Therefore, the study has been applied in two different field research projects, which featured the same objective at large – protecting and restoring biodiversity thanks to lighting infrastructure transformation – but different narratives, stakeholders and application methods involved.

Apart from the author, the two field projects were totally independent as they were not involving the same institutions, companies, social groups, professionals nor territories. The disciplines represented, though, were common, with a conscious lack of sociological support in the projects' first phases. Citizens were however represented by local and regional authorities, neighbourhood committees and other civil society collectives engaged in the mobility and environment sectors.

The two application projects implicated field surveys for biodiversity inventories and lighting quality characterisation plus stakeholders engagement workshops.

3. Results

These two application projects have been successful in terms of dialogues openness and of collaboration level between the different expertise. The stakeholders' level of engagement has also been overall very satisfying, with varying level of positive attitude at the beginning but with a manifest improvement in the course of the projects.

The two projects led to the successful implementation of lighting masterplans. They however required more on-site field surveys and longer meetings with stakeholders, especially when taking the form of engagement workshops, than "traditional" outdoor lighting projects.

4. Conclusions

Throughout this study, it has been possible to demonstrate that multidisciplinary collaboration works, as much on the theorisation of a common framework as in the practical implementation of new urban lighting infrastructures. More time has been dedicated to the elaboration and design phases of the projects than in traditional partitioned way of working. That is conflicting with the current outdoor lighting market state: as a result, new tools should be made available to allow the close collaboration between the different disciplines and to accelerate the collective decision-making. A digital tool allowing the synchronised collaboration between experts and the visualisation of the lighting footprint and its impacts is therefore under development.

PO73

LED LIGHTING IN ROAD TUNNELS: STUDY OF THE INFLUENCE OF CORRELATED COLOUR TEMPERATURE ON VISIBILITY, SIMULATION OF ENERGY-EFFICIENT ADAPTIVE LIGHTING SCENARIOS

TALON, D.[1], DUMORTIER, D.[2], BESSON, S.[1]
[1] Centre d'Etudes des Tunnels, BRON, FRANCE, [2] ENTPE, Université de Lyon, FRANCE
dorian.talon@developpement-durable.gouv.fr

Abstract

1. Motivation, specific objective

LEDs are progressively replacing the High-Pressure Sodium (HPS) light sources often used in the entrance zones of road tunnels. This change from HPS to LED technology means accessing a better control of the luminous flux of the light sources. The entrances of road tunnels are generally very consuming in terms of lighting (during daytime). In fact, the road luminance levels in these zones are relatively high (up to a few hundreds of cd/m²), as the lighting installation must ensure the transition of the visual systems of the drivers from the very bright environment outside of the tunnel, towards the relatively dark one inside it. In order to meet the safety requirements, the dimensioning of the lighting installation must consider the worst outside conditions, i.e. when the outside environment is the brightest. It implies that if we cannot control the lighting installation, the luminous levels that it delivers will be oversized most of the time. The LED technology, contrarily to the HPS one, comes with an accurate gradation of the sources flux and an eased pairing with intelligent control systems. It means that the luminous levels in entrance zones could be adjusted in real time depending on the outside luminous conditions, but also on the traffic conditions (speed) and the state of the road (wet or dry pavement).

The use of LEDs in itself can provide energy savings, as the luminous efficacies of the sources are better than the ones of the HPS sources. However, this study also investigate (through computer simulations) the potential energy savings that could be achieved with a better control of the lighting installation.

These simulations are achieved on the Antony cut and cover tunnel (Haut de Seine, France), which is the site of experimentation of the DELTA project.

2. Methods

This study relies on the development of a dynamic model, which allows us to estimate the yearly energy consumptions of a lighting installation controlled through environmental and traffic conditions. The model has to simulate for one year the natural lighting of the access zone, as well as the artificial lighting inside the tunnel. The heart of the model is based on the ray tracing software Ocean. The simulation of natural light represents actual sky conditions of the chosen site, as it uses local satellite data combined with the ASRC Perez sky model to recreate every 15 minutes the lighting conditions outside the tunnel. The veiling luminances that affect the drivers approaching the tunnel are determined thanks to these simulated outside lighting conditions. In addition, local traffic and state of the ground data are used as input data for the model. Thus, the latter uses local satellite, traffic and state of the ground data as input parameters and deduces from them the need in terms of road luminance levels inside the tunnel. Practically, the model adjusts the road luminance need every quarter of an hour (best temporal resolution for the input data collected), during an entire year.

The main interests of the model are the use of real data specific to a study site, as well as the fact that it considers the interactions between the three studied parameters (outside lighting conditions, traffic conditions, and state of the ground conditions).

As stated above, we apply this dynamic model to the Antony cut and cover tunnel as an example. Different scenarios of control of the lighting installation are tested (better control of the installation through the natural lighting conditions, control through traffic conditions, and control through state of the ground conditions, i.e. wet or dry pavement), and the energy savings that could be achieved without impairing the safety of the drivers are evaluated.

This simulation phase is part of a work linked to the DELTA project. One of the goal of the project is to recreate the control scenarios developed during this phase, in real conditions, and to compare the results obtained with the ones collected through simulations. This comparison will allow us to quantify the uncertainties that come with the simulations.

3. Results

The simulation results obtained with the dynamic model for the example of the Antony cut and cover tunnel shows that, in comparison to the current practices in terms of control of the lighting installation, annual energy savings around 15% are achievable with a better control of the installation through the natural lighting conditions. Around 35% are achievable with a control of the installation through traffic conditions and around 25% with a control through state of the road conditions (wet or dry pavement). In total, the energy savings can reach 58% if all these controls are used simultaneously.

4. Conclusions

The dynamic model shows that significant energy savings could be achieved through a better control of the lighting installation. These results constitute a first step, and will be compared to the ones obtained during the DELTA project, once they are produced. Concerning this project, it gathers many actors of the tunnel lighting field, in order to create an experimental platform in a real tunnel (Antony cut and cover tunnel). The main goal of this project is to study the potential impacts of the LED technology on tunnel lighting. Therefore, it also aims at characterizing numerous other impacts of this technology in tunnel, in addition to the gradation of the sources flux (impact of uniformities on visibility, impact of CCT on visibility, impact of the walls, impact on glare, …).

PO85

HEADLAMPS FOR OUTDOOR WORK IN DARKNESS

Bieske, K.[1], Vandahl, C. [1],Hubalek, S.[2], Schierz, C.[1]
[1] Technical University of Ilmenau, Ilmenau, GERMANY, [2] Social Accident Insurance for the Energy, Textile, Electrical and Media Products Sector (BG ETEM), Cologne, GERMANY
karin.bieske@tu-ilmenau.de

Abstract

1. Motivation, specific objective

Work in darkness requires lighting to enable people to see while working. Whereas it often can be stationary, there are workstations e.g. at construction sites for railway tracks and catenary where the lighting needs to be more flexible and therefore mobile. Maximum flexibility is required when during night climbing up a mast for troubleshooting and repairs in the rail network. Since there are catenary wires near the workers and both hands are needed when climbing and working, headlamps are the only lighting solution for safety reasons.

As the usage of headlamps as the one and only light source, contradicts existing law requirements, we needed to define minimum standards for those lamps carefully. The ANSI FL1 standard was a first approach for describing them, but soon turned out not to be detailed enough. Another challenge was, that nowadays there seems to be a kind of “the brighter the better” competition among the manufacturers of headlamps - which contradicts the needs of dark-adapted eyes, essentially orientating in a dark surrounding.

2. Methods

For good vision and to avoid accidents, the lighting requirements must be optimal designed. After initial theoretical considerations, we analysed applications, activities and visual conditions in the field of construction sites. Then, a study was designed and conducted with 22 test persons (40 – 75 years, Mean value: 45, SD: 5 years) in a laboratory test set-up. Three different tasks were investigated: work within the handle area, walking in the railway tracks and orientation in the track bed as well as fixation of grounding rods. Different luminous levels and luminous intensity distributions of headlamps were tested. In addition, glare through workpieces and even more important through headlamps of the colleague who sometimes also works on the mast, was considered. Based on the results, minimum requirements were defined.

3. Results

Headlamps should have several different light modes to enable the adaptation of light output and light distribution to the different tasks. They have to be flicker-free. If the luminous flux is high, vision in the illuminated area improves, but at the same time the risk of glare increases. Additionally, vision in the dark surrounding environment is reduced and the capacity of the battery decreases. Therefore, there is no such thing as the optimal luminaire. Instead, a compromise has to be found between the requirements for luminous flux, luminous intensity distribution, operating time and handling, whereas glare and disturbances of dark adaptation need to be avoided.

With these parameters we looked for an appropriate headlamp on the market – without success. Fortunately, a manufacturer was found who modified some of his existing headlamps. These prototypes were subsequently tested in the field. 19 test persons (27 - 61 years, mean value: 42 years SD: 11 years) in three companies tested the luminaire in a work context during the night shift.

4. Conclusions

Based on these findings an occupational safety standard for headlamps when climbing up a mast was worked out. We would like to discuss our findings and suggest additional

standardization on top of the existing ANSI FL1. This should be beneficial for headlamps in brighter environments and for pocket lamps, too.

MATHEMATICAL CONSIDERATIONS FOR ROAD REFLECTION PROPERTIES

Boucher, V.[1], Muzet, V.[2], Iacomussi, P.[3]
[1] Cerema, Light and Lighting Research Team, Les Ponts-de-Cé, FRANCE, [2] Cerema, ENDSUM Research Team, Strasbourg, FRANCE, [3] INRIM, Applied Metrology and Engineering, ITALY
vincent.boucher@cerema.fr

Abstract

1. Motivation

To design and control road lighting systems, the road lighting community deals with a dedicated coordinate system adapted to the different lighting situations and users. It defines the relevant lighting and viewing angles that describe how the road surface is lit by several different luminaires and viewed by drivers or pedestrian. These angles are dedicated to road lighting calculations made by convention with an observation angle fixed at 1°. However, since many years, some studies claim the need to consider other observation angles and geometries. In addition, numerical simulations of illuminated scenes require road optical properties measured not only for one viewing angle. For example, it is necessary to consider several observation angles for the visualization of road scenes, the evaluation of reflected illumination in tunnels or autonomous driving simulation and testing.

The mathematical function that describes the reflectance spatial distribution of a surface is called Bidirectional Reflectance Distribution Function (BRDF) and is measured with gonio-reflectometers. BRDF is usually defined in the cartesian frame using spherical coordinates with the illumination and viewing directions identified each by two angles. The BRDFs of materials are commonly used in computer graphics domain. In road photometry, only partial BRDFs are measured. The road surface BRDF value is denoted by the luminance coefficient, *q,* defined as the ratio of the viewed luminance coming from the road surface over its illuminance. Road surface *q* values are measured only at given angles ranges, the most relevant for road lighting, and stored as tables (namely *r*-tables) providing values for the two relevant lighting angles. Unfortunately, due to historical reasons the specific road photometry angles are defined in a different way than BRDF ones, with different lighting and viewing angles definition. Since the road surface characterisation is no longer limited to road lighting community, the angles definition discrepancies prevent information sharing between the communities and we need common conversion relations.

In road photometry and road surface characterisation, one additional parameter used to characterise the surface lightness is the average luminance coefficient Q0 defined in CIE TR 144:2001. It is the average of *q* values over a solid angle corresponding to a rectangular field of a road surface under a single street luminaire. This definition leads to several difficulties:

- Integration on a rectangular area with a polar coordinate system is complex. The calculation is approximated using weighting factors defined in the seventies and still present in CIE TR 144:2001. Their explanation cannot be found as it has not been published.
- In the *r*-table, some values are set to zero, because it was not possible to do it with the first measuring device. Due to the limited capacity of this first apparatus, many q values are not included in the table, while more illumination angles could be considered with actual devices.
- The considered integration area is only relevant for one road user: a driver. In the future, it will be possible to measure the null values and/or consider other illumination angles and with the actual weighting method methodology, it will not be possible to compute Q0.

2. Methodology and results

Once that CIE angles are defined without ambiguity, it is possible to compare them to the spherical angles. The paper provides a complete definition of the four CIE angles used for road surface characterisation and deduces relations to convert CIE road lighting coordinates to BRDF spherical coordinates. The CIE road lighting angles are represented for several street luminaires arrangements and the mathematical connections to convert CIE coordinates to spherical coordinates and reversely are provided. These relations will be useful to integrate road lighting data into computer graphics simulations, clarify and provide a coherent geometrical description in material gonio-reflectometer characterisation.

Concerning Q0 calculations, the paper proposes a new definition of the solid angle for the integration. Ω_0 is the solid angle containing all lighting directions with non-zero values in a q-table. A mathematical integration over Ω_0 approaches the Q0 values calculated as in CIE TR 144:2001 (weighting method) by less than 5%. This methodology is also validated with lighting design computation considering the seven CIE reference lighting situations and a database of pavements. This represents an alternative and more robust mathematical method instead of CIE TR144:2001 suggested weighting method. The obtained values are close to the 'old' Q0 system. So, it provides the best compromise between mathematical rigour and previous customary approach.

3. Conclusions

With the proposed conversion from road reflection classical geometrical convention to BRDF one, a unified and unambiguous approach is proposed that both works for road and marking reflection characteristics). It should facilitate sharing between the different communities: Physics optics, Computer graphics, Virtual reality. The proposed calculation of the average luminance coefficient Q0 could be applicable for classical r-tables and also for extended r-tables (without null values or with more values).

PO108

LIGHTING CONDITIONS FOR THE VISIBILITY OF OBJECTS ON THE ROAD SURFACE DURING TUNNEL DRIVING

Ikeda, Y.[1], Kunitomi, S.[1], Ikuta, K.[1], Jinno, M.[1]
[1] Ehime University, Matsuyama, JAPAN
yikeda@mayu.ee.ehime-u.ac.jp

Abstract

1. Motivation

We are investigating lighting conditions to improve the visibility of fallen objects in tunnels. We have also previously reported on visibility assessments when subjects are stationary. However, the effect of the subject's state of motion with the vehicle on visibility was unknown. This study evaluated the visibility of fallen objects during simulated driving using a VR device and a tunnel model.

2. Methods

This study evaluated the visibility of fallen objects during simulated driving using VR equipment and a miniature tunnel model (1:24 scale) with LED lights installed. The road surface was prepared with an asphalt-like colour. The LED lights consisted of two different types of luminaires. One of their light distribution characteristics is pro-beam distribution, and the other is symmetrical distribution. The illuminance on the road surface occupied by the pro-beam varied by 25% from 0% to 100%. The luminance of the road surface was set to a constant 4.5 cd/cm^2, in line with Japanese standards for road lighting installations. The angle between the direction of the pro-beam and the vertical line (pro-beam angle) was kept constant at 45°. The subjects were 11 students from our laboratory. They rated visibility on a scale from 0 (none) to 3 (high). Subjects watched a video of the vehicle driving through the model tunnel, previously recorded by a VR180 camera through an HMD (vive pro: HTC).

3. Results

With the subjects stationary, visibility evaluations were first performed. The experiment evaluated a 20 cm square fallen object's visibility at 100 m from the issue at a 1/24 scale. Visibility was then evaluated under the same conditions using HMD. The visibility evaluation points increased linearly to the natural logarithm of the luminance ratio calculated by (luminance of the fallen object display)/(luminance of the background road surface). The slope of the straight line was slightly lower with the HMD than with direct viewing and through the HMD. Although the slopes differed, we concluded that the HMD-mediated evaluation method could be sufficiently used to evaluate visibility.

A vehicle equipped with a VR180 camera was then driven through the 1/24 scale tunnel model at a speed equivalent to 80 km/h on a 1/1 scale, and the footage was recorded. As a result of pseudo-driving through the HMD, the results of the visibility evaluation were constant (difficult to see) for almost all luminance ratios. On the other hand, the distance from the subject to the fallen object, in case the just fallen object is visible, increased linearly with the natural logarithm of the luminance ratio. These results made it possible to determine the luminance ratio required for visibility at a sufficient distance to avoid fallen objects. For example, if a vehicle moves at a constant speed of 80 km/h and sees a fallen object at a distance of 80 m, it has 3.6 seconds to avoid a collision. Visibility evaluations using HMD have shown that the luminance ratio required is around 3. However, the results of the visibility evaluation with HMD tended to show a higher luminance requirement than with direct viewing. Therefore, the future must compare the visibility evaluation using HMD with actual vehicles and tunnels.

4. Conclusions

This study evaluated the visibility of fallen objects during simulated driving using a VR device and a tunnel model. As a result of pseudo-driving through the HMD, the results of the visibility

evaluation were constant (difficult to see) for almost all luminance ratios (luminance of the fallen object display)/(luminance of the background road surface). On the other hand, the distance from the subject to the fallen object, in case the just fallen object is visible, increased linearly with the natural logarithm of the luminance ratio. These results made it possible to determine the luminance ratio required for visibility at a sufficient distance to avoid fallen objects.

PO111

EVALUATION OF DISCOMFORT GLARE IN ROAD LIGHTING USING FIXED LOW MOUNTING HEIGHT LUMINAIRES

Maehama, T.[1], Futatsuya, H.[2], Kawamata, T.[1], Miyamoto, K.[3], Hayakawa, M.[3], Ito, H.[1],
[1] Nexco-East Engineering Co. Ltd., Tokyo, JAPAN, [2] Panasonic Corp., Osaka, JAPAN,
[3] Nippon Expressway Research Institute Co. Ltd., Tokyo, JAPAN
t.maehama.sa@e-nexco.co.jp

Abstract

1. Motivation, specific objective

On Japanese expressways in Japan, it is necessary to take countermeasures against the fall of road-related facilities installed at high positions for the safety of road users and road workers. Also, due to the declining working population in Japan, the efficiency of maintenance operations is required more efficient. Road lighting has mainly adopted the pole lighting system, in which luminaires are installed at a height of around 10m above the road. In order to solve the above-mentioned social issues, the adoption of a fixed low mounting height luminaires lighting system in which luminaires are installed at a height of about 1m from the road is increasing. Compared to the pole lighting system, the fixed low mounting height luminaires lighting system, in which the luminaire is installed at a position closer to the driver's viewpoint, causes more discomfort glare. However, a method for evaluating discomfort glare for fixed low mounting height luminaires lighting system has not been established. Therefore, this paper proposes a lighting design index and its permitted value for evaluation of discomfort glare in road lighting using fixed low mounting height luminaires lighting system.

2. Observations

In the darkroom, one luminaire used for the fixed low mounting height luminaires lighting system was installed at an angle of 45 degrees from the observation position. Observers fixed their gaze on the image of road lighting using fixed low mounting height luminaires lighting system projected by the projector in front and adapted to 0.5 to 3.0 cd/m^2.

Observers adjusted the luminous flux of the luminaire by themselves to set the maximum luminous flux that permitted discomfort glare. Observation was carried out at three levels of distance between the observer and the luminaire, considering the width of the shoulder of road, and the observer set the maximum luminous flux that permitted discomfort glare five times under the same conditions. After the observer sets the maximum luminous flux of the luminaire that is permitted discomfort glare, the experimenter measured the vertical surface illuminance GEv in the direction facing the luminaire set to maximum luminous flux. The observers were 12 men in their 20s to 50s.

3. Results

GEv showed significant differences among observers, so after excluding GEv from the third quartile to 1.5 times the interquartile range of all GEv measurements, 75% of all observers GEv permitted by was derived as the permitted value. Correlation between GEv and observer's adaptive luminance was shown on both logarithmic scales. It was also shown that GEv varies depending on the distance between the observer and the luminaire. The maximum permitted value of GEv in the shoulder of road width range of 0.5m to 3.0m was 30 lx or less.

4. Conclusions

In road lighting design using fixed low mounting height luminaires lighting system, discomfort glare can be suppressed by considering luminous intensity distribution, luminous flux, and luminaire installation angle so that GEv is less than the permitted value. Also, the permitted value of GEv is set according to the average road surface luminance and the shoulder of road width.

PO117

VISIBILITY TO DRIVERS OF PEDESTRIANS CROSSING A ROAD WITH A PRO-BEAM ROADWAY LIGHTING SYSTEM

Kohko, S.[1], Takahashi, Y.[1], Hagiwara, T.[2], Sagane, Y.[3], Kurosawa, M.[4], Hama, Y.[4]
[1] Iwasaki Electric Co., Ltd., Tokyo, JAPAN, [2] Hokkaido University, Sapporo, JAPAN, [3] Association of Electricity and Telecommunication Engineering for Land and Infrastructure, Tokyo, JAPAN, [4] Ministry of Land, Infrastructure, Transport and Tourism, Tokyo, JAPAN

kouko-shunsuke@eye.co.jp

Abstract

1. Motivation, specific objective

The National Police Agency of Japan analyzed the circumstances of fatal road accidents from 2017 through 2021. It reported that pedestrian versus motor vehicle accidents are more numerous and more frequent at night and in the twilight than in the daytime.

The authors considered that traffic accidents could be mitigated by creating a visual environment in which drivers could see pedestrians crossing an intersection in positive contrast. Based on that idea, field experiments were conducted to examine the relationship between the brightness and the visibility of pedestrians crossing the road, in order to elucidate how a lighting system can make pedestrians more visible by putting them in positive contrast.

2. Methods

2.1 Experiment installation

With the aim of quantitatively understanding the relationship between the visibility and the brightness of pedestrians, a pedestrian crossing and an intersection were created on a test track. In experiments conducted there, participants were asked to evaluate the visibility of pedestrians crossing the intersection. Two conditions were provided. Under one condition, pedestrians were visible in negative contrast; under the other condition, pedestrians were visible in positive contrast.

The experiments were conducted at a four-way intersection on a two-way road with left-hand traffic. Road lighting for symmetrical luminous intensity distribution and pro-beam lighting (referred to as PBL below) were used.

2.2 Experimental method

To understand the relationship between the brightness and the visibility of pedestrians crossing the intersection, participants in a standing vehicle observed pedestrians and gave subjective evaluations of visibility level on a scale of 1 to 7 and risk level on a scale of 1 to 5.

a) Evaluations made when pedestrians crossing the road were visible in negative contrast

For the evaluations, the illuminated range on the road surface and the lighting pattern of headlights were varied. The illuminated area on the road surface served as the background when the participants in a car that was oriented as if traveling straight ahead saw the pedestrians. On the assumption that the test track was an ordinary road, the distance between the participants and the pedestrians was 40m, a safe stopping distance for a vehicle traveling at 40km/h.

b) Evaluations made when pedestrians crossing the road were visible in positive contrast

In the experiments on positive contrast, a right-turning car and a left-turning car were assumed in addition to the car assumed to be traveling straight ahead. By using PBL and a

spotlight (SP), the vertical illuminance at a height of 0.8m above ground level where the pedestrian stood was adjusted to 2, 5, 10, 20, or 40 lx.

In the experiments using the straight-traveling car, the distance between the participant and the pedestrians was 40m, as in the case of the experiments on negative contrast, and 55m was also used as a safe stopping distance for a car traveling at 50km/h.

3. Results

1) Evaluations of negative contrast

When the pedestrians were visible in negative contrast and low-beam headlights were off, 75% of the participants evaluated the risk level as ‘1: risky’ or ‘2: slightly risky.’ Regarding the evaluations made of the pedestrian standing at the lane edge (indicated by the left-hand bars), fewer participants evaluated the pedestrian as ‘1: risky’ and more participants evaluated the pedestrian as ‘4: slightly safe’ when the low-beam headlights were on than when they were off.

When the background of the pedestrians was illuminated for a distance of 35m, 79% of the participants evaluated the visibility of the pedestrians as between ‘1: largely invisible’ and ‘3: slightly invisible’. When the background of the pedestrians was illuminated for a distance of 70m, a majority of the participants evaluated the visibility level as ‘3: slightly invisible’. This result clearly indicates that even when the background of the pedestrians is illuminated for a distance of 70m, the driver perceives risk and has difficulty seeing the pedestrian in negative contrast. Because the 70m illumination range is considered to create a background large enough for pedestrians to be recognized, it is suggested that ‘3: slightly invisible’ could be the highest visibility evaluation when pedestrians are visible in negative contrast.

2) Evaluations of positive contrast

Two evaluation scales were used for evaluating the visibility of the pedestrians crossing the road. A strong positive correlation was found between these two scales. When the risk level was ‘3: acceptable’, the visibility level was ‘4’, which was between ‘3: slightly invisible’ and ‘5: slightly visible’.

This study is associated with the preceding studies as follows: The visibility levels 3, 4 and 5 are associated with vertical illuminances of 3.5 lx - 8.4 lx, 5.0 lx - 11.0 lx, and 15.0 lx - 25.0 lx, respectively.

4. Conclusions

With the aim of clarifying the illumination effect of road lighting on the visibility of pedestrians under the condition that pedestrians are visible in positive contrast, the relationship between the visibility of pedestrians and the photometric quantity of lighting intensity were examined. The findings are stated below.

When the pedestrians were visible in negative contrast, 75% of the participants evaluated the risk level as ‘1: risky’ or ‘2: slightly risky’, and 79% of the participants evaluated the visibility level as between ‘1: largely invisible’ and ‘3: slightly invisible’. Additionally, it was suggested that ‘3: slightly invisible’ could be the highest visibility evaluation when pedestrians are visible in negative contrast.

When pedestrians were visible in positive contrast, it was found that enhancing the vertical illuminance above the crosswalk helped raise visibility and risk to acceptable levels. Specifically, it is desirable to be able to recognize pedestrians crossing intersections in positive contrast. Thus, the adoption of pro-beam road lighting is highly likely to mitigate traffic accidents. The experiments described above proved that when the vertical illuminance toward the driver at a height of 0.8m above ground level ($Ev_{0.8}$) is around 7.5 lx, the pedestrians in the intersection are visible at the visibility level of ‘4’, a level higher than ‘3: slightly invisible’, which is the highest level under the condition that pedestrians are visible in negative contrast.

PO143

PROPOSAL OF MAINTENANCE MANAGEMENT METHOD FOR ROAD LIGHTING FACILITIES USING UNMANNED AERIAL VEHICLES

Takahashi, Y.[1], Kohko, S.[1], Hagiwara, T.[2], Sagane, Y.[3], Kurosawa, M.[4], Hama, Y.[5]
[1] Iwasaki Electric Co., Ltd., Tokyo, JAPAN, [2] Hokkaido University, Sapporo, JAPAN
[3] Association of Electricity and Telecommunication Engineering for Land and Infrastructure, Tokyo, JAPAN, [4] Ministry of Land, Infrastructure, Transport and Tourism, Tokyo, JAPAN
[5] Kanto Regional Development Bureau, Saitama, JAPAN
takahashi-youhei@eye.co.jp

Abstract

1. Motivation, specific objective

Road lighting improves safety for drivers, riders, and pedestrians. In order to achieve the positive effect of road lighting, it is necessary to maintain the recommended amount of light by replacing lamps that no longer work and by periodically cleaning optical components such as lenses and glass that have become dirty. LED lighting, which has rapidly spread in recent years, has a long life and the amount of light gradually decreases over time, making it difficult to determine when to perform maintenance on lighting fixtures.

Therefore, with LED road lighting, it is necessary to periodically check whether the brightness of the road surface is maintained at the recommended amount of light. The recommended amount of light is calculated as recommended road surface luminance based on key factors such as road type, speed limit, average daily traffic (AADT), and surrounding environment. Road surface luminance is obtained either by measuring the road surface luminance with a luminance meter or by measuring the horizontal surface illuminance of the road surface with an illuminance meter. However, to measure road surface luminance or illuminance, it is necessary to stop traffic on the road to be measured. Therefore, it is desired to establish a simpler and quicker method to measure the road surfaces luminance.

Unmanned aerial vehicles (UAVs) are attracting attention as equipment that can fly freely in the airspace as low as 200 m from the ground. Industrial UAVs have begun to be introduced in the fields of surveying, logistics, and disaster recovery. Industrial UAVs are equipped with an advanced autonomous piloting system that provides superior flight control. In addition, the performance of UAVs has been improving in terms of flight time and shooting distance. Aerial photography in the industrial field using UAVs is becoming easier. If a UAV can measure the recommended light level on the road surface from above the road, it can be used for road lighting maintenance. As a result, the time required for traffic control can be shortened and the burden on road users can be reduced. In this study, we proposed a maintenance method of road lighting using UAVs, and to clarify the measurement accuracy of road surface illuminance photometry using UAVs, we attempted UAV photometry of road surface brightness and illuminance under various lighting conditions, and verified the validity of the maintenance method.

2. Methods

2.1 Measuring equipment

The equipment used for the photography was a UAV, a digital SLR camera with known tonal and luminance characteristics (wide-angle single-focal length lens), and a monitor for viewing the images from the ground.

2.2 Measurement target

Twelve roadway lighting conditions were measured, including four symmetric pole-top lighting conditions, five symmetric low-position lighting conditions, two pro-beam pole-top lighting conditions, and one pro-beam low-position lighting condition. The reflectance of the asphalt

pavement was approximately 6.9%. The reflectance of the road was measured using a spectrophotometer.

2.3 Measurement Method

First, the UAV loaded with photographic equipment is placed in the center of the road surface brightness measurement area of the road to be measured. Next, the UAV is raised in the direction directly above the installation position, and the altitude of the UAV is set so that the entire road surface brightness measurement area is within the angle of view of the captured image. After the altitude is determined, the road surface luminance is finally measured from that position using image photometry. The measurement range was the distance between luminaires in the longitudinal direction of the road, and only the driving lane in the transverse direction of the luminaire.

Image capture by UAVs is performed with the aircraft hovering in the air. At this time, it is necessary to increase the exposure time of the camera if very low luminance is to be captured. When the exposure time of the camera becomes long, blurring occurs in the captured image due to the shaking of the UAV when it is hovering. Therefore, in this experiment, the lower limit of the road surface luminance that can be photographed was set to 0.2 cd/m^2 in order to avoid the effect of shaking when the UAV is hovering. The photometric road surface luminance was converted to road surface illuminance using the previously measured reflectance of asphalt pavement.

3. Results

The road surface luminance measured by the UAV ranged from 0.31 cd/m^2 to 0.60 cd/m^2, which translates into an illuminance range of 11.9 lx to 24.6 lx. On the other hand, the illuminance of the road surface measured by the illuminance meter ranged from 15.4 lx to 29.5 lx.

The UAV measurements were uniformly about 20% lower than the illuminance measured by the illuminance meter. The correlation coefficient between the two measurements was 0.97, indicating a strong positive correlation. One of the reasons for the difference between the two measurement results may be that the road surface brightness measured by the UAV was converted to road surface illuminance, assuming the road surface to be a uniformly even diffuse surface. Since the management of road surface brightness can be done by relative comparison over time, these results suggest that the road surface illuminance acquired by the UAV can be used for the maintenance and management of road lighting facilities.

4. Conclusions

In order to clarify the measurement accuracy of road surface illuminance photometry using UAVs, road surface illuminance photometry using UAVs was performed in various lighting environments with different light distribution and lighting systems, and compared with the values measured by illuminance meters. The results showed that the values were uniformly about 20% lower, and the correlation coefficient between the two was 0.97, suggesting that UAV-based road surface illuminance metering can be used for maintenance and management of road lighting facilities. We will continue to work on improving the accuracy of road surface illumination photometry using UAVs.

PO147

AN EXPLORATORY STUDY TO ASSESS OUTDOOR LIGHTING IN URBAN CONTEXTS CONSIDERING IMPLICATIONS ON HUMAN HEALTH AND WELLBEING

Valetti, L.[1], Piccablotto G. [2], Taraglio R. [2], Pellegrino, A.[1]
[1] Department of Energy 'Galileo Ferraris', TEBE Research Group, Politecnico di Torino, ITALY
[2] Department of Architecture and Design, Analysis and modelling of environmental system Laboratory, Politecnico di Torino, ITALY
lodovica.valetti@polito.it

Abstract

1. Motivation, specific objective

Contemporary social habits and economic needs involve the night hours considerably more than in the past, thus promoting a continuous fruition of urban spaces. Therefore, research on artificial light at night (ALAN) has been largely expanded in past years. Outdoor lighting is considered an essential service and offers many benefits to users, such as increased safety, visibility and comfort, attractive spaces, social interaction, promotion of activities, etc. However, the use of artificial lighting also implies negative effects in terms of environmental and energy impacts, and research suggests that excessive exposure to ALAN may have adverse effects on human health and wellbeing, disrupting the biological clock and the nocturnal production of melatonin. The 'sum total of all adverse effects of artificial light' is defined within the CIE International Lighting Vocabulary as 'light pollution'. In the past decades, rapid urbanization increased the quantity and concentration of ALAN, mainly due to human activities for exterior, street, and façade lighting, and lead to an uncontrolled increase of light pollution in the environment. Improper design solutions of lighting systems, inappropriate light distribution from luminaires as well as light reflected from illuminated surfaces can significantly affect the living conditions of people, particularly in urban contexts due to the high intensity of ALAN. Nowadays many indications and recommendations, among which the WELL Community Standard, stress the importance of potential adverse effects of light on human health and regulation of circadian rhythms, promoting the adoption of strategies that allow to reduce unnecessary lighting and curtail obtrusive light and light trespass.

Based on this framework the assessment of light pollution is an important challenge. Studies on light pollution are currently mainly based on the analysis of nighttime satellite imagery, representative of sky brightness, and based on the evaluation of the phenomenon on the horizontal plane. However, the assessment of the quantity and the spectrum of light on vertical planes (i.e., users' eyes, building facades, etc.) is more relevant when the influence on people is considered, since it represents the effective dose of light that impacts the human visual system.

In this paper, an exploratory study based on a defined methodological approach for the assessment of the artificial light at night in a city context was conducted. The study was based on a case study and involved the assessment of light pollution through the analysis of both satellite imagery and in-field measurements (photometric and spectral measurement campaign) in some significant and recurrent urban conditions. The approach allowed therefore to analyse data referring both to horizontal and vertical planes.

The aims of the study were (i) to define a methodological approach to evaluate the electric light at night through both satellite imagery and in field measurements; (ii) to analyse an urban context based on the defined methodological approach, obtaining data from satellite imagery and in-field photometric and spectral measurements and (iii) to evaluate and compare the results from the two analysis approaches. The electric lighting conditions in some recurrent and typical urban areas were assessed, considering the impacts of different parameters, such as urban structure, road typology, geometry and technical characteristics of the lighting system.

2. Methods and results

In the paper results of the application of a methodological approach devoted to the assessment of the ALAN on a case study are presented.

First, the case study was analysed based on some parameters, such as the urban structure (characteristics and height of the building's facades), characteristics of the lighting system (type of light sources and luminaires, installation geometry), width and geometry of the streets, etc. Based on this analysis an abacus of recurring and typical urban scenarios was defined and specific significant areas were selected for the subsequent in-field analysis.

Then, light pollution was assessed based on a dual approach: (i) analysis of the nighttime satellite imagery and of the data that can be obtained from this kind of tools and (ii) in-field measurement campaign in the selected pilot areas to acquire both photometric and spectral data on different reference planes (horizontal and vertical). Luminance distribution and illuminance measurements were acquired to assess the lighting conditions within the nocturnal scene. Moreover, a spectrophotometer was used to analyse the spectral characteristics of the light at people eyes.

Finally, satellite data and data obtained from in-field measurements were compared. Moreover, through the comparison of results related to the different typical scenarios, the impacts of different conditions, such as the characteristics of urban structure and lighting system, on light pollution were evaluated.

3. Conclusions

The paper presents a study in which an assessment method was applied to a case study to evaluate electric lighting conditions at night considering both horizontal and vertical directions. The inclusion of vertical planes through in-field measurements in the evaluation of light pollution can allow extending the research concerning the effects of ALAN on human comfort and health. Moreover, the assessment of the impacts of different urban and lighting system characteristics on light pollution can contribute to the definition of indications for architects and lighting designers towards the design of sustainable lighting systems that allow also to reduce the impact of excessive ALAN.

PO158

RESEARCH ON THE DEVELOPMENT PATH OF KEY TECHNOLOGIES BASED ON SMART LIGHT POLE SYSTEM

Zang, F.[1], Huang, L.B.1[1] Liu, L.[1]
[1] Nanjing Lighting Construction and Operation Group Co., Ltd, Nanjing 210019, CHINA
781854707@qq.com

Abstract

1. Motivation, specific objective

This paper aims to provide future oriented suggestions on the construction and development of smart city infrastructure, promote the development of digital economy and the industrial ecological reconstruction of information infrastructure, and comprehensively support the modernization of urban governance system and governance capacity.

2. Methods

This paper starts with the relationship between smart light poles and smart cities, through the analysis of the development characteristics and trends of smart light poles, the system architecture and its key technologies are systematically sorted out, and deeply discusses the development path of key technologies based on smart light poles system.

3. Results

This paper discusses the development path of key technologies based on smart light poles system from the following aspects: from function dispersion to high integration, from smart node to smart ecosystem, from fixed scenario to flexible scenario, from software definition light poles to software definition world, from data standards to data governance.

4. Conclusions

The new generation of information infrastructure represented by smart light poles has become an important carrier to improve the energy level and core competitiveness of cities, and also a key enabler to promote the development of digital economy. In order to comply with the development trend of the new generation of information infrastructure, we should reconstruct the industrial ecology and information infrastructure with software, knowledge, intelligence and modularization, form the strategic infrastructure resources at the city level, and comprehensively support the modernization of the urban governance system and governance capacity.

PO162

AIRBORNE LUMINANCEMETER FOR OBTRUSIVE LIGHT MEASUREMENTS

Chasseigne, R., Renoux, D., Pierrard, S., Garcia-Marquez, J., Valin, T., Betis, P., Hay, B., Dubard, J
[1] Laboratoire National de Métrologie et d'Essais LNE, Trappes, FRANCE
romain.chasseigne@lne.fr

Abstract

1. Motivation, specific objective

Obtrusive light is the content of anthropogenic artificial light in a dark environment emitted in any non-required direction. Frequently, the street lighting and illumination sources are reported to affect astronomical observations, zoological life, and, generally speaking, the outdoor environment. There is also a quantity of obtrusive light that goes beyond the lighting area, referred to as intrusive light; this kind of light affects human beings. Some animal species may be sensitive to light emitted outside the visible spectrum. Lamps used for lighting have a spectrum that can extend from UV to IR although new LED lamp spectra can be limited to the visible spectrum. Different research bodies are currently involved in obtrusive light studies; astronomers have investigated the sites where telescopes operating in the visible part of the EM spectrum should be installed. Excessive lighting cause an additional sky brightness impeding most of the lower magnitude stars from being observed. Zoologists have also been interested in the effects of excessive light on birds' migration, the light polarisation disturbances it may provoke on certain insects' navigation systems, and the attraction some of them manifest for lamps. As reported in scientific publications, obtrusive light effects also concern reptiles, mammals, and marine life.

Obtrusive and intrusive light alters the circadian rhythm of human beings. A change in the circadian rhythm can cause sleep disorders and potentially may lead to health condition deterioration, including obesity, diabetes, depression, and psychological disorders.

Obtrusive light concerns have alerted French members of the Parliament, whose actions led to new laws and ministerial decrees. By limiting obtrusive light, these laws and decrees look to rationalize artificial light, dealing with energy consumption reduction and biodiversity preservation. In this context, the authors are working on a new airborne luminance meter to evaluate the light emitted from the ground toward the sky with technical specifications that must comply with French laws and decrees.

The work presented, part of a French project, involves designing and manufacturing an airborne instrument capable of measuring the ground's vertical luminance and the colorimetric characteristics–such as the colour temperature–of street lamps and illumination sources.

2. Methods

The instrument is based on a camera and is designed for airborne missions. In such circumstances, the quantity of interest is the luminance [$cd\cdot m^{-2}$]. Cartography of a 1000 km^2 area requires hundreds of images and inertial sensors to consider the aeroplane's yaw, pitch, and roll. The instrument shall identify colour temperatures as the ministerial decree has set 3000 K as the limit, even less in some specific cases.

The project's objectives shall be met through the following steps:

1. Luminance meter design;
2. Ground-based photometric reference sources measurement;
3. The metrological assessment considers atmospheric conditions, geo-referencing, signal processing, and instrument calibration.

The main component of the new luminance meter is a matrix sensor camera that should provide a satisfactory signal-to-noise ratio. The camera is calibrated in (a) its Y tri-stimuli

component response in grey levels $GL \cdot cd^{-1} \cdot m^{-2}$, (b) its linearity and signal-to-noise ratio, (c) its geometric distortions, and (d) the uniformity calibration. The camera is equipped with Y, Z, X1, and X2 filters; thus, the camera plus filter responsivity is also characterised.

3. Results

First tests and calibrations permitted us to effectively find a camera capable of obtaining an excellent signal-to-noise ratio, given the flight conditions. An absolute test bench was built to carry out the multiple calibrations: Response Y in $GL \cdot cd^{-1} \cdot m^{-2}$, linearity, and geometrical distortions. The camera-filter spectral responsivities were obtained for each of the four filters.

4. Conclusions

The first results of the luminance meter are encouraging. The test bench and calibration results are presented. Calibrations in our laboratory have shown the viability of using such an instrument as an airborne luminance meter that meets the mission requirements derived from the French laws and decrees concerning the limitation of the obtrusive light. Based on the laboratory experience in airborne-based remote sensing, the mechanical structure to couple the instrument to its dedicated place in an airplane has been designed and is under manufacture.

PO165

THE IMPACT OF LIGHT AND DARK ON CRIME IN LONDON

Erturk, E.[1], Unwin, J.[1], Raynham,P.[1]
[1] University College London, London, The UNITED KINGDOM
ezgi.erturk.21@ucl.ac.uk

Abstract

1. Motivation, specific objective

The study examines the number of crimes that take place in daylight and after dark and what types of crimes are more common after dark.

2. Methods

The methodology relies on the calculation of the solar altitude at the time the crime took place, for that reason it was only possible to study crimes where the time was known to have taken place in a window of 5 minutes or less. Thus, the method could only be applied to about 45% of reported crimes. The study looked at the weeks on either side of the clock change associated with the change to summertime and back again.

The study used a database of the reported crimes from the London Metropolitan Police Service (MPS) for the years 2013 to 2019. For each crime, the database gives the crime type the location, and the time window in which the crime took place. After some data cleaning, we considered 4 728 291 crimes and found that there were 2 145 398 crimes where the time was known within 5 minutes.

A previous study had shown that it was reliably dark when the sun was more than 6° below the horizon and reliably light when the sun was above the horizon. Comparison of crime rates in darkness the week one side of the clock change and in daylight at the same time in the week the other side of the clock change, or vice versa, enables the identification of types of crime that are likely to be affected by external lighting conditions

3. Results

Whilst across the whole day there are more crimes during daylight than at night in the comparison periods we identified about 4.8% more crimes in the dark.

However, the increase in crime in the dark was not uniform across all crimes with some crimes like the reported possession of drugs decreasing in the dark. On the other hand, the crimes of Criminal Damage, Residential Burglary, Robbery of Personal Property, Theft from the Person, and some Vehicle offenses all showed a significant increase in the dark.

4. Conclusions

The results show that whilst there is an overall change in crime rate after dark there is a significant change for some types of crime. Moreover, the nominal reduction in some types of crime may be associated with the fact that the crime is harder for the Police to spot in the dark, for example, drug offenses. The crimes studies all have particular spatial patterns throughout London and this gives further opportunities to study the relationship between light and crime.

PO173

VISIBILITY PERFORMANCE OF LOW POSITION ROAD LIGHTING SYSTEM

Sagane, Y.[1], Hagiwara, T.[2], Imai, T.[3], Tahata, T.[3], Hamaoka, H.[4], Sakata, N.[1], Kurosawa, M.[5], Hama, Y.[6]

[1] Association of Electricity and Telecommunication Engineering for Land and Infrastructure, Tokyo, JAPAN, [2] Hokkaido University, Sapporo, JAPAN, [3] KOITO ELECTRIC INDUSTRIES, LTD. Kanagawa, JAPAN, [4] Akita University, Akita, JAPAN, [5] Ministry of Land, Infrastructure, Transport and Tourism, Tokyo, JAPAN, [6] Kanto Regional Development Bureau, Saitama, JAPAN

y-sagane@kendenkyo.or.jp

Abstract

1. Motivation, specific objective

A low position road lighting system is effective to prevent collapse and drop of ancillary road facilities in the event of accidents and disasters, provide ease of inspection and produce less light pollution. With these backgrounds, the low position road lighting system, which are installed at a height of about 1.2 m, is being tried in various highways in Japan. The reason why it is still on trial is that the standards for this low position road lighting system have not been established in the Japanese standards for the installation of road lighting facilities. Thus, we conducted a field experiment to examine visibility performance of the low position road lighting system in comparison with the common pole road lighting system. In near future, based on these experimental results, we propose recommended standards for the low position road lighting system.

2. Methods

The field experiment was performed up at the test track on the dry asphalt surface to comprehensively compare the visibility performance of the low position road lighting system and the pole road lighting system.

[Road lighting system]

- Low position road lighting system: 13 units at 10 m intervals, luminaire height 1.2 m, and LED road lamps with symmetrical light distribution.
- Pole road lighting system: 4 units at 40 m intervals, luminaire height 10 m, LED road lamps with symmetrical light distribution.

[Measurements]

- Horizontal luminance on the lane between two luminaires by the image photometry.
- Horizontal illuminance on the lane between two luminaires by the illuminance meter.

[Subjective assessment]

- Visual target : 20 cm x 20 cm flat plates with reflectance of 5%, 10% and 20%.
- Participants: 10 people in their 20s with 2.3 years of driving experience.
- Subjective visibility assessment: The participants rode on front two seats of an observation vehicle. Three visual targets were placed in front of the observation vehicle at 75 m ahead. The observation distance was 75 m at a safe stopping distance at a design speed of 60 km/h. The participants answered "Yes" or "No" to the presence of each of three targets. Presentation time of the three visual targets was 1.0 seconds approximately.

- Discomfort glare : Discomfort glare was evaluated by placing the observation vehicle in front of the luminaires along the road and in the center between two luminaires, setting the vertical surface illuminance at 1.2 m height above the edge line at 50 lx, 25 lx, and 12.5 lx respectively. The participants rode on front two seats of the observation vehicle evaluated the discomfort glare in both stationary and driving conditions.

3. Results

3-1 Results of Optical Performance

(1) Low position road lighting system

Average horizontal luminance between two luminaires was 1.37 cd/m2. The average horizontal illuminance was 17.1 lx, and uniformity was 0.33. Also, the lane axis illuminance uniformity was 0.56. In addition, luminance contrasts of the visual targets were measured. In case of 5% and 10 % reflectance, luminance contrasts were silhouett. In case of 20% reflectance, luminance contrasts of the visual targets were reverse silhouette.

(2) Pole road lighting system

Average horizontal luminance between two poles was 0.95 cd/m2. Average horizontal illuminance was 15.4 lx, and uniformity was 0.56. Also, the lane axis illuminance uniformity was 0.37. In addition, luminance contrasts of the visual targets (reflectance: 5%, 10%, and 20%) were silhouett.

3-2 Results of subjective visibility assessment

(1) Visibility probability of the visual targets

Visibility probability of the visual targets is defined as "Correct response rate", which means number of correct response divided by total number of response. Measured visibility probability was 98% and 97% respectively for the low position road lighting system at 5% and 10% reflectance conditions. Luminance contrasts of the visual targets were silhouett. In case of 20% reflectance, luminance contrasts of the visual targets were reverse silhouett, and measured visibility probability was down to 73%. Meanwhile, measured visibility probability was 81%, 84% and 80% respectively for the pole road lighting system at 5%, 10% and 20% reflectance conditions. All luminance contrasts of the visual target were silhouett.

(2) Total Revealing Power

The visibility performance for two road lighting systems was quantified using TRP (Total Revealing Power). Value of TRP showed over 75% at all of three reflectance conditions of the visual targets for the low position road lighting system. Value of TRP showed over 68% at all of three reflectance conditions of the visual targets for the pole road lighting system. TRP for the low position road lighting system showed slightly better visibility performance than that for the pole road lighting system.

(3) Discomfort glare

Discomfort glare for the low position road lighting system was lower than middle point (acceptable) of the evaluation scale under both of the stationary and driving conditions when the vertical illuminance at a height of 1.2 m above the edge line was less than 25 lx.

4. Conclusions

The low position road lighting system used in the field experiment showed the same level of visibility performance as the common pole road lighting system. Based on results of the field experiment, it is supposed that recommended standards for the pole road lighting system might be applicable as recommended standards for the low position road lighting system. However, it is required to consider visibility performance in case of reverse silhouett of the visual target because the luminaire is located close to the road and installation height of the luminaire is low. Also, it is necessary to understand the reflective performance of the pavement surface assuming the low position of the luminaire. Including these issues, it is necessary to finalize the lighting standards with the low position road lighting system.

PO07

USING DYNAMIC LIGHT TO REGULATE SLOW OSCILLATIONS OF BRAIN TO IMPROVE SLOW WAVE SLEEP AND MEMORY CONSOLIDATION

Chen, Y-S.[1], Yang, C-M.[2], and Chen, C-Y.[1]
[1] Graduate Institute of Colour and Illumination Technology, National Taiwan University of Science and Technology, Taipei, TAIWAN, [2] Department of Psychology, National Chengchi University, Taipei, TAIWAN
chencyue@mail.ntust.edu.tw

Abstract

1. Motivation, specific objective

Slow oscillations refer the cortex and thalamus neurons express continuously oscillate in synchronous network patterns in the form of slow fluctuate activities(<1HZ). Many studies have shown that slow oscillations are related to slow-wave sleep and memory consolidation mechanisms. There are two main sources for initiating full network cortical layer activity via slow oscillations: one is through constantly active pacemakers that activate cortical neurons, and the other is through spontaneous synaptic activity that randomly initiates activity. In this study, we focus on using direct thalamic stimulation to evoke slow oscillations-triggered states, where the slow oscillations generated by external stimuli interacts with other high-frequency oscillations in the brain. This mechanism, which uses slow oscillations as the basic frequency, can promote the proliferation of delta waves during slow-wave sleep. Among various stimuli, light is considered the simplest method. This study will use a continuously changing light source with dynamic colour temperatures (<1HZ) as an external stimulus to promote the slow oscillations and observe its relationship with memory consolidation. If the relationship between dynamic light sources and slow oscillations can be proven, with a long-stable impact, the dynamic light can provide support for improving sleep quality and memory consolidation.

2. Methods

This experiment recruited 19 volunteers who underwent three one-hour napping sessions during midday. The volunteers slept in a room adapted for sleeping and were exposed to slow dynamic colour temperature and fixed colour temperature light environments during the sleep experiment. Polysomnography (PSG) was used to record their brainwaves throughout the experiment to observe the effects of dynamic colour temperature on the volunteers' NREM sleep EEG changes. Furthermore, two types of word pairing memory tests were carried out under the two different light source environments to observe the impact on memory consolidation.

3. Results

The hypothesis of the experiment is that dynamic colour temperature light sources can increase delta wave activity during NREM sleep. The experimental results showed that there was an increase in slow wave activity during NREM period with the dynamic colour temperature light source, but there was no significant difference in word-pair memory test.

4. Conclusions

There are many ways to induce slow oscillations through external stimuli, such as auditory stimulation, transcranial direct current stimulation (tDCS), and pharmaceutical agents. Among these methods, auditory stimulation has the least invasiveness, but older adults may have problems with its efficacy and tolerance due to hearing impairment. Transcranial direct current stimulation has good tolerance, but the device has limitations in terms of wearing and environment. Light stimulation has a simple signal, and unlike sound or current, it is less affected by individual differences in tolerance. At the same time, it can also avoid inherent

restrictions on hearing impairment and wearing space and environment of transcranial direct current stimulation devices. The results of this study confirm that dynamic light is one way to regulate the slow oscillations during NREM sleep.

PO25

NON-IMAGE FORMING HUMAN RESPONSES TO DIFFERENT LIGHTING CONDITIONS IN BUILT ENVIRONMENT: PRECISE MEASUREMENTS

Malovrh Rebec, K.[1], Biček, A.[2], Oblak, A. [2], Krhin, B. [2]
[1] Slovenian National Building and Civil Engineering Institute, The Department of Building Physics, Dimičeva 12, Ljubljana, SLOVENIA, [2] University Medical Center Ljubljana, Department of Nuclear Medicine, Zaloška 7, Ljubljana, SLOVENIA
katja.malovrh@zag.si

Abstract

1. Motivation, specific objective

Several diseases such as obesity, diabetes, depression, heart disease, weakened immune system, and cancer have been reported to be possible consequences of sleep disturbance, hormonal imbalance, and impaired circadian rhythm. Important modulators of circadian rhythm are melatonin and cortisol, which are strongly affected by the intensity and wavelength of the light observer is exposed to. Consequently, one of the important causes of impaired circadian rhythm may be daylight and electric lighting design practices in the modern world. Lighting also represents around 22 % of total energy use in buildings and is therefore one of the key factors for sustainable, decarbonized, and energy-efficient building design. It is very important to determine, where, when, and what quality and quantity of light is needed in the building, to propose an efficient and also human-centric solution with the health and well-being of occupants in mind. However, lighting design research is rarely coupled with healthy living and working environments aspects measured in a very precise way. Thus, we propose a systemic approach for digitalized artificial lighting design with the aim of bringing energy and resource efficiency into buildings and at the same time addressing human health and well-being needs through non-image-forming aspects of lighting. The motivation for our study is to report participant cortisol and melatonin responses with precise lighting conditions measurements in the built environment and to propose a novel model to report it.

2. Methods

In our pilot study, 10 participants were included, and the cohort was later expanded to 30 participants. All participants complied with inclusion and exclusion demographic and living habits criteria (age, gender, wake-sleep habit, food, food supplement, and medication intake, etc.). To obtain relevant individual participant circadian rhythm entrainment signals by measuring hormone responses in a precise way, we have first established laboratory settings mimicking workspace which was the basis for group assignment findings. Spectrally tunable lighting was being applied and daylight was blocked. Some of the previous studies confirmed that different light sources which emit similarly looking white light (expressed with correlated color temperature in Kelvins) can cause quite different non-image forming effects. The saliva samples were collected throughout the day to determine precise fluctuation rates of hormones. Immunoassays were used to determine saliva melatonin and cortisol levels, which were correlated with the light measurements. Lighting conditions were captured in the gaze direction with a spectroradiometer and optical fiber.

3. Results

The first measured results show distinct hormonal responses at different lighting conditions and are promising a novel approach to the standardization of lighting conditions in the built environment. We have developed a model, where hormonal responses are related to exact lighting conditions, but we have also considered individual sleep and wake patterns. As expected, age played a role in our findings, but more importantly, lighting was a major factor to help support natural hormonal balance and circadian rhythm.

4. Conclusions

Human body function and well-being within the built environment are strongly dependent on appropriate lighting conditions. During the day, the light intensity and its spectral power distribution should mimic daylight phases as much as possible to prevent hormonal imbalance, disrupted circadian rhythm, and sleep. Those impairments are often related and followed by obesity, diabetes, depression, heart diseases, weakened immune systems, and cancer. With the digitalization of the construction sector and unprecedented options for designing light sources, we can design and use lighting that will support individual needs to support image and also non-image-forming need of the human body.

PO38

SIMULATION OF ALPHA-OPIC CORNEAL IRRADIANCE ACROSS DIFFERENT HEAD SHAPES USING PHYSICALLY REALISTIC SPECTRAL RENDERING

Nakade, U.[1], Krug, C.[1], Evgin, R.[1], Spitschan, M[1,2]
[1] Technical University of Munich, Munich, GERMANY, [2] Max Planck Institute for Biological Cybernetics, Tübingen, GERMANY
manuel.spitschan@tum.de

Abstract

1. Motivation, specific objective

Light exposure is a critical factor affecting the circadian rhythm in humans. Numerous studies have shown that a disturbed sleep cycle can lead to physical and mental health problems. Electric lights and phone screens used at night can cause significant exposure to short-wavelength light and supress melatonin production. To design better light environments, it is essential to address questions such as: How do light positions and spectra affect the amount of short-wavelength light reaching the eyes? What is the influence of the reflectance spectra of the objects around us? How do head shape and skin reflectance affect the exposure? By leveraging physically realistic spectral renderings of everyday environments, we aimed to answer these questions.

2. Methods

We built realistic 3D models of everyday scenes in Blender, corresponding to different categories, including apartment and office space. We also built a novel dataset of spectral reflectance functions of commonplace objects, from our own measurements and gathered from a variety of published sources. We placed all the spectra and the objects into categories and sampled the spectra randomly. We used Mitsuba3, a rendering system for light transport simulations, to produce spectral radiance images, which were later converted to α-opic radiance images. We then used a low-dimensional parametric head shape model and various skin reflectance spectra to study how they affected light exposure. We varied the position of a light source and assessed its impact on corneal irradiance.

3. Results

Our simulations produced a series of novel insights into how light exposure varies with environment and headshape attributes. We find a dependence of simulated corneal irradiance on various parameters of the head shape model. The results of these simulations will be presented.

4. Conclusions

Spectral rendering tools and realistic models of the environment and head shape can open a new way of performing light exposure experiments. Building on these results, we can also explore how eye movements affect light exposure and how we can modify our environments for a healthier light dose.

PO86

THE ROLE OF SPATIAL DISTRIBUTION IN METRICS FOR NON-VISUAL RESPONSE TO LIGHT

Bonavia, S.[1], Unwin, J.[1], Raynham, P.[1]
[1] University College London, London, UK
simone.bonavia.15@ucl.ac.uk

Abstract

Environmental light exposure affects not only the visual system but also the non-visual system. While there is now some agreement on the spectral weighting used to evaluate light that triggers non-visual responses, research on the impact of the spatial distribution of light remains limited. Many researchers rely on measuring illuminance or irradiance at the cornea, which may oversimplify how the stimulus is characterised. The non-uniform distribution of intrinsically photosensitive retinal ganglion cells (ipRGCs) and the photoreceptors that contribute to their response, implies that visual fields with identical corneal illuminance but contrasting spatial distributions may lead to different retinal responses. Additionally, the size of the pupil varies across individuals, directly affecting how much light reaches the retina.

This study proposes a methodology to test the hypothesis that spatial distribution is relevant when characterising light for the non-visual system. The proposed methodology uses pupillary response as the outcome measure and scenes with varying light distributions as the stimulus. High dynamic range imaging is leveraged to evaluate a theoretical retinal response as a function of scene luminance. The comparison of pupil response to retinal response correlations with pupil response to corneal exposure correlations will indicate whether the characterisation of light for non-visual effects research should consider the spatial distribution of light and pupil size.

A pilot laboratory experiment is currently underway to test this hypothesis, and preliminary results are expected to be available at the time of the conference.

PO106

VALIDATION OF DIURNAL CIRCADIAN LIGHTING ACCUMULAITON MODEL BASED ON A LIGHT HABIT SURVEY OF 448 CHINESE PATICIPENTS

Hou, D.[1], Lin, C.[2], Wang, J.[1], Lin, Y.[1,2]
[1] Human Phenome Institute, Fudan University, Shanghai, CHINA, [2] Department of Light Sources and Illuminating Engineering, School of Information Science and Technology, Fudan University, Shanghai, CHINA
ydlin@fudan.edu.cn

Abstract

1. Motivation, specific objective

Diurnal circadian lighting accumulation (DCLA) model is a new predictor of human circadian phase shift (CPS), constructed by the diurnal light exposure characteristics, including timing, duration and the ipRGC-based light dose corresponding to human circadian time. This study aims to validate the DCLA model through a large-sample light habit survey without experimental intervention in Chinese population.

2. Methods

The light habit survey is composed of six parts: basic information, living environment, daylight exposure habit, artificial lighting exposure habit, visual display terminal exposure habit, and subjective circadian phase shift characteristics, which has high test-retest reliability (TRR = 0.710) and validity (Cronbach's α = 0.819).

723 people participated in the online survey, 275 questionnaires were excluded due to lighting professional background, logic errors and abnormal filling (garbled characters), and 448 valid questionnaires were obtained. The participants covered multiple age groups, from ⩽ 25 years old to ⩾56 years old. In terms of gender, male participants accounted for 47.77%, female participants accounted for 52.23%, and the ratio of male to female was close to 1:1. In addition, the chorotype of the participants covered all five types from definite evening to definite morning according to the score of Morningness-Eveningness Questionnaire.

In terms of questionnaire item quantification: a) the items related to the circadian stimulus (light source type) were calculated by simplifying the characteristic spectrum, such as CIE D65 represents daylight; CIE F1 represents cool fluorescent lamps, etc.; b) the physical time was converted into circadian time to calculate the DCLA according to participant's chorotype; c) the CPS was quantified by the amount of change in the midpoint of sleep calculated from sleep and wake-up time. Then, the DCLA and the corresponding CPS of each participant were obtained. Correlation analysis between predicted CPS and subjective CPS was conducted to explore the accuracy of the DCLA-CPS model.

3. Results

According to the analysis results, the light exposure before waking up ($p < 0.001$), the bedroom CCT ($p < 0.001$) and other light habits show significant correlation with subjective CPS. For the model validation, it can be found that the prediction of the DCLA-CPS model in the CPS direction is accurate, but there are deviations in the prediction of the CPS magnitude. It shows a better predictive effect on the CPS of -1 h~1 h, there is a slight deviation between the predicted results and the subjective results on the larger circadian phase shifts (-2 h and 2 h). This deviation may be caused by an inappropriate interval of options for the subjective CPS setting. In general, the predicted CPS and subjective CPS also show a significant correlation with $R^2 = 0.7884$ ($p < 0.05$).

4. Conclusions

This study validated the applicability and predictive accuracy of the DCLA-CPS model in a larger population with five chorotypes. In addition, the scope of the DCLA-CPS model was extended from artificial lighting to all light entering the eye, including daylight, artificial lighting, and the light from displays.

PO120

RESEARCH OF DISINFECTION EFFECTIVENESS OF DIFFERENT UV SPECTRUM

Qiuhua Wei[1], Jie Han[1], Sishuo Sha[1], **Jin Li**[2], Yuying Liu[2]
[1] Chinese People's Liberation Army Center for Disease Control and Prevention,Beijing, CHINA, [2] Beijing Scitlion Technology Cop., LTD, Beijing, CHINA
214261418@qq.com

Abstract

1. Motivation, specific objective

In recent years, due to the ongoing global outbreak of emerging infectious diseases caused by pathogenic microorganisms, especially the new coronavirus pneumonia pandemic, which has seriously affected human health safety and social development, the people's awareness of health and epidemic prevention has been significant enhanced significantly .As important vectors, ambient air and object surfaces are the transmission routes of pathogenic microorganisms that cannot be ignored. With the emergence of various new disinfection technologies, new ideas have been proposed on physical disinfection methods by means of special wavelength light irradiation. Physical disinfection has the advantages of high efficiency and broad spectrum, no pollution, no chemical residue, etc., and the proposal of 222nm ultraviolet technology has greatly expanded the potential application field of ultraviolet disinfection.This research is going to provide a technical basis for the development and application of different wavelengths of ultraviolet rays, in the same time provide reliable technical means for the prevention and control of infectious diseases.

2. Methods

In this paper, the carrier quantitative sterilization test method was used to study the inactivation effect of three different wavelengths of ultraviolet rays (222 nm, 254 nm and 275 nm) on representative microorganisms under different environmental conditions and on different carriers respectively

3. Results

The limited inactivation dose of different wavelengths of ultraviolet irradiation on different microorganisms and its environmental impact factors were concluded

4. Conclusions

Through the data obtained, it can support designers to reasonably select ultraviolet products and technologies of different wavelengths in different application scenarios to achieve satisfactory disinfection effects

PO124

THE MEASUREMENT UNCERTAINTY OF THE IMAGING LUMINANCE MEASUREMENT DEVICES

Motyčka, M.[1], Škoda, J.[1]., Baxant, P.[1]., Novák, F.[1]
[1] Brno University of Technology, Brno, CZECH REPUBLIC
motyckam@vutbr.cz

1. Motivation, specific objective

The luminance camera based on CMOS or CCD sensor is type of imaging luminance measuring device that is capable of the luminance measurement in every pixel of captured image. The conventional luminance meter only measures average luminance in its defined viewing angle in one direction. The imaging luminance measuring devices offer more flexibility and complexity to the luminance analysis of captured scenes. However, these devices are very complex in order of hardware and software calibration and the uncertainty analysis is therefore more difficult than in case of the conventional luminance meters. In this article a reader learns about the measurement uncertainties estimation of imaging luminance measurement device based on the DSLR camera. This can help both users to better understand the device and help to set parameters of the device for the lowest possible expanded measurement uncertainty and also for developers to find standard uncertainties that can be lowered during the calibration or measurement.

2. Methods

For uncertainty analysis the GUM is used for statistical evaluation of residual uncertainties of necessary corrections of ILMDs. To verify estimated expanded uncertainties the comparative measurement of the tested devices against the calibrated reference device is performed. There is also possibility to change lenses of ILMDs devices for specific application. For the UGR evaluation of the scene and light pollution measurement it is necessary to use the FishEye lens with the half-space viewing angle. On the contrary in case of the measurement of street luminaires it is appropriate to use the lens with longer focal length in order to achieve more detailed luminance distribution map. Due to the spectral sensitivity of standard photometric observer these devices can be also used for the measurement of traffic signs and illuminated advertisement without significant spectral errors. Each measurement requires different settings of the camera. This article proposes a method of uncertainty of measurement analysis and estimation for all types of lenses, where the estimation and confirmation of standard uncertainties can be slightly different.

The luminance cameras must undergo complex hardware and software calibration to achieve the low measurement uncertainty and can compete with the conventional luminance meters and spectroradiometers. The measurement uncertainty depends on the settings of the camera like shutter speed, aperture number and focus distance. Moreover, the measurement uncertainty varies within the captured image and therefore uncertainty should be evaluated for every pixel of the image. The non-uniformity of expanded uncertainty is mainly dependent on the lens. In this article the most significant measurement uncertainties are described and estimation of expanded uncertainties of the luminance camera is presented along with the recommendations of presenting the measurement uncertainty.

3. Results

CIE 244 Characterization of Imaging Luminance Measurement Devices (ILMDs) proposes good methods how to qualify the different ILMDs with several indexes. However, these indexes do not represent standard measurement uncertainties. Therefore, this paper shows correlation between these indexes and standard uncertainties for chosen luminance camera. Moreover, in this paper there is described a new method based of well-known index f_1' to qualify more sophisticatedly the measuring device as luminance camera where this index changes across the image.

4. Conclusions

As a result, the 3D functions are chosen to best represent expanded uncertainty across the image for each camera's settings. implementation of these functions into the measuring software can be beneficial in the future both for the users and also for developers of these devices.

PO156

THE INFLUENCE OF MOBA GAME WORK ON ACTION VIDEO GAME PLAYERS' VISUAL FUNCTION, COGNITIVE FUNCTION AND VISUAL FATIGUE IN LOW-ILLUMINANCE E-SPORTS LIGHT ENVIRONMENT

Yan, Y.[1,2], Zhang, J.[1,2], Cheng, X.[1,2]
[1] Faculty of Architecture and Urban Planning, Chongqing University, Chongqing, CHINA, [2] Key Laboratory of the Ministry of Education of Mountainous City and Towns Construction and New Technology, Chongqing University, Chongqing, CHINA
yanyonghong@cqu.edu.cn

Abstract

1. Motivation, specific objective

During e-sports, athletes highly rely on a single visual channel to quickly pick up and sort information, the proportion and severity of CVS caused by e-sports operations are higher than other types of VDT operations. Due to the different contents of visual work, VDT office work lighting design standards are not applicable to the e-sports work light environment. The lack of e-sports lighting design standards makes the current situation of the light environment of the e-sports training space worrying. Through the statistical analysis of the survey results of the e-sports training space in 5 China cities and a series of comparison experiments, this paper evaluates the potential cumulative risks of the light environment to the teenagers, warns the risks of the dangerous light environment. Through these experiments, by utilizing the characteristic of which MOBA can improve players' spatial perception resolution, contrast sensitivity and other visual functions under certain conditions, we try to explore the threshold boundary of training intensity, duration, light switching and other factors that can stimulate players to play a positive role. This paper suggests the suitable range of illumination for MOBA game training. This paper also provides a systematic solution to clarify the complex interaction of man-machine-environment. Trying to eliminate the accumulation of fatigue of e-sports players, reduces the health risks of long and continuous VDT screen dynamic lighting on the future of teenagers, promotes the formulation of health protection standards and lighting design standards for e-sports space, and push forwards the standardization and standardization of architectural design of e-sports training space.

2. Methods

The light environment survey of e-sports training space was conducted in 5 Chinese cities. We recorded the illumination level of the e-sports game spaces and the Action video game players' preference for the screen luminance and background luminance, and conducted statistical analysis of the data; 40 Action video game players' were selected as the experimental objects, and the preference characteristics of the subjects on the e-sports light environment were studied through the autonomous dimming experiment, we obtained the median preference illuminance of the operation surface.

The subjects' visual function and cognitive function performance in different length of working hours were compared under the two difference illuminance levels of 300lx and 75lx, the former is the general VDT office workplane recommended illuminance in *Standard for lighting design of buildings GB 50034-2013* and *Lighting of Indoor Work Places CIE S008 / E-2001*, while the latter is the subject's preferred illuminance.

1)MOBA game task light environment preference experiment in e-sports training space

The experimental subjects were 40 healthy male Action video game players aged 18-25, and the test competition level was comparable, all of which reached the high level of diamond of League of Legends bright diamond or above. The subject dictated the requirements for the horizontal illuminance of the desk, and the experimenter conducted remote dimming through the software on another computer until the requirements of the subject were met to establish the preferred light environment and record it. The experimenter reset the dimming mode of

the lamp after each adjust. Before the dimming of each subject, the experimenter will reset the dimming mode of the lamp.

2)The influence of different MOBA game training duration on the visual system in the preferred light environment

Sixteen 18-25-year-old male Action video game players with normal or corrected-to-normal vision, right-handed, no history of nervous system disease were selected to complete the contrast experiment for two weeks at 300 lx and 75 lx workplane illuminance matching screen luminance and background luminance. Before each experiment and 1h, 2h , 3h after e-sports training, measured the visual functions such as flash fusion frequency, remote visual acuity and visual sensitivity, as well as cognitive performance such as visual attention, cognitive flexibility, reaction time, working memory and visual search. Fill in the subjective evaluation scale and KSS scale.

3. Results

1)The median workplane illuminance of subjects for the light environment of MOBA game training is 73.6lx, which is significantly lower than the minimum recommended value of 300 lx for general VDT office lighting in *Standard for lighting design of buildings GB 50034-2013* and *Lighting of Indoor Work Places CIE S008 / E-2001*;

2)The average preferred screen / background luminance ratio of the subjects is 2.627, and the too high luminance ratio will aggravate the visual fatigue of the subjects;

3)Subjects appear better visual function and cognitive performance, and less visual fatigue at 75 lx workplane illuminance than at 300 lx, but the results are not statistically significant;

4) In both light environments, MOBA games showed the improvement to the subjects' visual and cognitive function but also caused visual fatigue. The positive effects are to temporarily improve the subjects' contrast sensitivity and distant vision, and temporarily improve the participants' visual attention, working memory and visual search ability.And the negative effect is causing slight visual fatigue.

5)At 75 lx workplane illuminance level, the appropriate training time length threshold boundary for the MOBA game operation is 2 hours.

4. Conclusions

It is not appropriate for the e-sports training space lighting to directly apply the VDT office lighting design standards. From the perspective of energy saving, the lower workplane illuminance level of 75 lx is more appropriate. When the training time is controlled within 2 hours, MOBA game work is beneficial to the improvement of players' visual function and cognitive function, and its long-term impact remains to be further studied.

PO160

COLOUR CONSTANCY FOR LOW-ILLUMINANCE SCENES BASED ON BRIGHT REGION

Yi, X.[1], **Lin, Y.**[1,2*]
[1] Institute of Future Lighting, Academy for Engineering and Technology, Fudan University, Shanghai 200433, CHINA, [2] Institute for Electric Light Sources, School of Information Science and Technology, Fudan University, Shanghai 200438, CHINA
ydlin@fudan.edu.cn

Abstract

1. Motivation, specific objective

Colour constancy calculation plays a pivotal role in process of image signal processing as "white balance". Despite of rich body of literature on colour constancy calculation, the colour problems of low-illuminance scenes are much less concentrated. Unlike pictures captured under normal illumination, low-light pictures are usually of poor visual quality. Because of more noise and larger areas of darkness, the performances of methods applied to daytime images also degrade when they are applied directly to low-light images. To address this issue, we focus on the colour constancy calculation and dataset for scenes which are with low illumination and uneven light.

2. Methods

In this paper, an illuminant estimation method is proposed for low illuminance scenes based on lightness-weighted region. The images are first transformed from RGB space to La^*b^* space and divided into regions of fixed size. When the lightness of pixels exceeds T percentile (from 80% to 95%) of other pixels, the pixels are defined as top-lightness pixels. Then, regions, where more than half of the pixels are top-lightness pixels, are selected. Finally, neutral pixels statistics methods are utilized in the selected region to estimate the illuminants of the scene. Meanwhile, in this work, a new dataset for low-illuminance scenes is established. The dataset includes 112 raw images in different scenes, 86 of which are outdoor scenes. The illuminance in the set is generally between 0.1 lx and 50 lx.

3. Results

The performance of the algorithm is evaluated by angular difference. Our experimental results on the low-illuminance dataset show the proposed method outperforms other unsupervised methods. The best 25% of angular error is 0.63. The results of other colour constancy methods on low-illuminance scenes were compared and analysed as well. The proposed method is also tested on the ColorCheckerRECommended dataset for normal illuminance scenes and shows comparative results with some supervised methods. The region constraint can also be used as a post-processing stage for other colour constancy methods to improve its accuracy.

4. Conclusions

In this paper, a method that combines lightness-weighted region and neutral pixels statistics method is proposed. The selective bright regions can efficiently reduce the impact of noise and dark areas in low-light images. Our method is simple, intuitive, and does not need to occupy too many computing resources, so it is suitable for deployment in the digital camera in the current mobile terminal. For low-illuminance scenes, the problems of pseudo-neutral pixels and multiple illuminants are still worthy of further research.

PO163

TIME-SEQUENTIAL RGB IMAGING WITH A MULTISPECTRAL ILLUMINATION SOURCE AND A GATED CMOS CAMERA

Coosemans, J., Iranian, P., Ingelberts, H., Kuijk, M., Jacobs, V.A.
Vrije Universiteit Brussel, BELGIUM
Jan.Matei.Coosemans@vub.be

Abstract

1. Motivation, specific objective

There are many well-established ways of capturing an image of an arbitrary scene with a CMOS camera and reproducing an accurate RGB color image, ready to be displayed on a screen. The most common one is the use of Bayer patterned filters, where every pixel is dedicated to capture a specific part of the visible spectrum, e.g. 'red', 'green', 'blue', etc. Because of this spatial filtering, information is lost and the full resolution of the camera is not exploited. In some imaging and image recognition applications, e.g. biomedical imaging, imaging for autonomous vehicles, etc., it is crucial to optimise the resolution of the RGB image in order to distinguish very small features.

Besides Bayer-based color cameras, there exist several other approaches to create full resolution RGB images. One is the three-sensor approach, which consists of three separate cameras, each dedicated to either the 'red', 'green' or 'blue' part of the visible spectrum which is filtered by a trichroic prism. Although this approach results in a full resolution RGB image, the setup is very costly.

Another approach is time-sequential color filtering, which filters the incoming light in the time domain by using a tunable filter and captures the three colors at their corresponding times by gating the camera. This time-sequential filtering requires the camera system either to be rather large and complex (i.e. color filter wheel) or very expensive (i.e. Fabry-Perot based color filters).

The objective of this work was to develop a novel RGB imaging system, where the filtering is performed at illumination side, not at camera side. This is done by designing an illumination source which is able to generate consecutive 'red', 'green' and 'blue' light pulses and using a time-gated camera which captures the reflections of the pulses on the scene, respectively. This makes it possible to keep the camera system itself as compact as possible, while still maintaining full resolution RGB images.

2. Methods

The illumination source was designed by using a setup of beam splitters, RGB colored transmission filters, lenses and optical fibers. Starting from a white laser source, a pulse is emitted and split into three 'arms' by using beam splitters. Next, a colored transmission filter is placed in every arm to filter the spectrum of the pulses into R, G and B, respectively. Here, the selection of the transmission spectra of the filters is crucial w.r.t. providing a good Color Rendering Index (CRI) of the illumination source. Then, the pulses in every arm are coupled into an optical fiber, each with a different length, in order to provide a time delay between the R, G and B pulses, relative to each other. Now, the pulses are separated in both the time and space domain. In order to recombine the three pulses in space, a fiber coupler is used. This provides one single output for the illumination source emitting the 'red', 'green' and 'blue' pulses consecutively. These pulses are then illuminated on a scene, reflected and consecutively being captured by a time-gated CMOS camera which is synchronised with the time of arrival of the pulses. Hence, the camera captures three images in full resolution representing the raw RGB data of the scene.

To generate an accurate color image of the scene on a display, a calibration is needed corresponding the spectra of the chosen RGB filters and the spectrum of the white laser. This

is done by using a standard colorchecker with labelled RGB coordinates. In order to calibrate the raw RGB coordinates, linear and polynomial regression was used and compared to one another.

3. Results

An accurate color image of an arbitrary colorful scene was already obtained. At the time of writing, the study is still ongoing and more tests are being done in order to provide more details on the full performance of the system. Hence, the final conclusions are expected after the analysis of the data.

4. Conclusions

In this work, a novel method of time-sequential RGB imaging, exploiting the full resolution of the camera, is presented. This is done by spatially, spectrally and temporally demultiplexing a white laser pulse into three pulses, each representing one of the RGB channels, and then multiplexing these again, to create one single illumination source. By synchronising a time-gated CMOS camera with the time of arrival of each pulse, 'red', 'green' and 'blue' images of the scene are consecutively captured. After calibration and post-processing an accurate RGB image is generated, ready to be shown on an RGB display. This way, it is possible to keep the camera compact and still obtain full resolution RGB images with a high accuracy.

PO174

MODELLING OF PERCEPTUAL GLOSS UNDER MIXED LIGHTING CONDITIONS

Tanaka, M.[1,2], Amari, S.[2], Horiuchi, T.[2]
[1] Graduate School of Global and Transdisciplinary Studies, Chiba University, Chiba, JAPAN,
[2] Graduate School of Science and Engineering, Chiba University, Chiba, JAPAN
midori@chiba-u.jp

Abstract

1. Motivation, specific objective

The topic of how to quantify the appearance that humans perceive from an object has been actively discussed. Recent studies have shown that perceptual gloss has psychological effects, such as increasing consumer interest, and the relationship between physical gloss and perceived gloss has been addressed. Although the gloss of an object can be physically measured using a gloss meter, physical gloss and perceived gloss do not necessarily match, and CIE JTC17 has also discussed gloss measurement and gloss evaluation methods. This study aims to derive a model for estimating perceptual gloss under mixed lighting conditions including high-directional and diffuse illumination.

2. Methods

Multiple regression analysis was performed using data obtained from visual evaluation experiments of perceptual gloss and measurements of physical properties related to physical gloss to derive a model.

2.1. Visual evaluation experiment

Perceptual gloss was assessed in two perceptual gloss evaluation experiments with different lighting (diffuse illumination only in a dome, or a combination of diffuse and high-directional illuminations) and viewing angle conditions. The background is grey, equivalent to Munsell value N5, and the viewing distance is 300 mm.

Experiment I: Participants evaluated the perceptual gloss of the experimental stimuli by looking vertically into the experimental stimuli through an observation window at the top of the dome, where the experimental stimuli were illuminated by diffuse illumination.

Experiment II: A small directional light was installed inside the dome to create an illumination condition in which diffuse and high-directional illumination were mixed. The angle of incidence of the directional illumination on the experimental stimuli was the same as for the gloss measurement, with three ISO-compliant angles (20°, 60°, and 85°). Participants evaluated the perceptual gloss of the experimental stimuli by looking through an observation window on the top of the dome at an inclined angle. The luminance of the illumination was dimmed to the same level as in Experiment I (40 cd/m^2).

The evaluation method used a magnitude estimation with the reference stimulus as 100 and no gloss as 0. No upper limit was placed on the evaluation value, and participants could always access the reference stimulus placed next to the experimental stimulus while evaluating. Until all the stimuli had been evaluated, participants repeatedly evaluated a randomly selected stimulus from among all the stimuli for evaluation with both eyes. Ten participants in their 20s with normal colour vision joined the experiments. The collected perceptual gloss evaluation data were analysed by the Smirnov-Grabs test to remove outliers, and then the mean values were used for modelling.

2.2. Samples

Experimental stimuli included ten different materials (paper, cloth, stone, metal, resin, rubber, glass, wood, leather, and ceramic). In Experiment I, using only diffuse illumination, 79 samples were used, and in Experiment II, using diffuse and directional illumination together,

97 samples were used. All samples treated in Experiment I were also treated in Experiment II, and the number of some samples was increased in Experiment II to make the model more generalizable. About half of the samples were transparent or translucent.

2.3. Measurement

To acquire physical properties such as reflection/transmission characteristics and surface structure of the samples, 13 physical characteristics were measured: (1) physical gloss (GU), haze, and distinctness of image (DOI) measured by a gloss meter, (2) reflectance, transmittance, lightness, hue, and chroma measured by a spectrophotometer, (3) five 2D luminance distribution features (contrast, dissimilarity, homogeneity, angular second moment, entropy) calculated by taking HDR images. Physical gloss and 2D luminance distribution features were measured at three angles (20°, 60°, 85°) following ISO standards.

By performing a multicollinearity test on the measured physical features, independent physical features with low correlation to other features were extracted and used in the analysis as explanatory variables in the modelling.

3. Results

The modelling results from multiple regression analysis showed that better accuracy was achieved using non-linear physical gloss than linear ones. Specifically, multiple regression analysis using the parameter α powered physical gloss and linear haze, DOI, and contrast as explanatory variables and perceptual gloss as the objective variable yielded a degree-of-freedom adjusted coefficient of determination of approximately 0.71 for the diffuse illumination condition in Experiment I. In addition, high coefficients of determination of 0.64 for 20°, 0.76 for 60°, and 0.82 for 85° were also obtained for the lighting conditions in Experiment II (diffuse and high directional illuminations). Compared to the coefficients of determination obtained from the modelling results using only nonlinear physical gloss, the improved coefficients of determination were observed for all lighting conditions, indicating that the accuracy of the estimation model has improved. On the other hand, there were some patterns in which haze and DOI were not significant, and the positive and negative signs of the regression coefficients of haze and DOI differed among the models, suggesting that haze and DOI had a relatively small effect on the modelling of perceptual gloss under some lighting conditions.

4. Conclusions

In this study, we modelled perceptual gloss by multiple regression analysis using various physical features and perceptual gloss obtained from visual evaluation experiments using experimental stimuli consisting of 10 kinds of material. Two lighting conditions were tested: diffuse illumination only, and a combination of diffuse and highly directional illuminations. We found that the coefficient of determination ranged from about 0.6 to 0.8, indicating that it is possible to estimate perceptual gloss from physical measurements with high accuracy. Further research is needed, including experimental design and modelling using colourful samples to consider the effect of colour more generally.

PO05

AN INNOVATIVE EFFICIENT FULL SCALE HORIZONTAL LIGHT PIPE

Beltrán, L.O.[1]
[1] Texas A&M University, College Station, TEXAS, USA
LOBeltran@tamu.edu

Abstract

1. Motivation, specific objective

This paper presents a passive solar horizontal light pipe technology that introduces daylight in multi-story deep floor plan buildings without the negative effects of occupant's glare and building's solar heat gains. The light pipe system was designed to deliver natural light in building cores (5-10m from window wall) using an optimized geometry and high reflective materials. The current light pipe system was developed for latitude 30ºN in a predominantly sunny and clear sky location with an annual 81% of clear and partly cloudy days.

The light pipe system is designed to be used in combination with a lower view window and be placed within the ceiling plenum with a collector that extends 0.25m from the building facade plane, so that it could be used with flush and articulated facades. It provides supplementary illumination at distances between 4.6m and 10m. The light pipe prototype uses a relatively small inlet glazing area, 0.3m by 1.5m (0.45m^2), to efficiently redirect sunlight at distances up to 12m from the window wall. Several reflectors are used to collimate incoming sunlight to minimize inter-reflections within the transport section of the light pipe, and to maximize the efficiency of the system. The pipe is coated with a 99.3% specular highly reflective film. At the end of the light pipe a diffusing radial film with 68-88% visible transmittance has been incorporated to distribute light uniformly.

2. Methods

The experimental facility consists of a 360º-rotating room that represents a section of a deep open plan office space of 3.0m high, 6m wide and 9.1m long. The facility is located in an open area with no obstructions around it. This paper presents the photometric measurements of the light pipe facing South. The space includes two sidelight windows of 2.74m wide by 1.52m high (4.16m^2 each) with Tvis of 51%. The windows have external moveable blinds with 0.8 reflectance. The interior surface reflectances are: ceiling 0.81, walls 0.88, and floor 0.15. The light pipe glass area is 5.5% of the sidelight windows.

Interior illuminance measurements were taken at twenty-five reference points at workplane height, 0.76m. Twenty-five cosine- and color-corrected LI-COR photometric sensors (LI-210SA) were placed over the workplane at equal distances, 1.5m to 7.6m from the window wall, at centerline. Outside the test room, two sensors were placed on the roof and façade to take global horizontal illuminance (GH) and global vertical illuminance (GV). Data was collected every 30 seconds for an entire year. The analysis of illuminance levels is based on 10 hours, 8:00 to 18:00 true local time (TLT), which is typical office building schedule.

HDR images were created using the programs Picturenaut 3.2 and Photosphere to assess visual qualities in the room. HDR images were created from eleven bracketed exposures to cover from 1-20,000cd/m^2. A Nikon Coolpix 5400 camera with a Nikon fisheye lens were used to capture a wide view of the space as well as the external conditions. False-color images were created from HDR images to visualize the spatial luminance distribution, and measure the luminance variability across the space. The program hdrscope was used to analyze glare at three locations in the room using Evalglare's Daylight-Glare-Probability (DGP) and Daylight-Glare-Index (DGI) glare prediction models.

3. Results

The light pipe and sidelight window provide natural light evenly distributed over the workplane and throughout the space. The space shows an overall uniform daylight distribution, the

sidelight window illuminates the front of the room and the light pipe illuminates the back. The high illuminance levels introduced by the light pipe at the back of the space (4.5m to 8.5m from the window wall) demonstrates the efficiency of the light pipe design, which with an opening of 1/18th of the sidelight window area provides 5-6 times higher illuminance levels than those provided by the sidelight window at the back of the space. A single light pipe is able to introduce adequate illuminance levels across a 6m wide space. Long-term illuminance measurements confirmed that the light pipe provides similar lighting levels at the back of the room as in areas adjacent to the windows; for example, at 1.5m from the window, light levels reach over 2,500lux while at the back of the space (beyond 6m) light levels reach over 2,000lux. Daylight delivered by the light pipe at the back of the space provides high illuminance levels of full-spectrum daylight in interior office cubicles or basement throughout the day.

HDR images were recorded and studied in detail at three locations in the space with the blinds up and down. Luminance levels at the back of the space (7.6m) under the light pipe are uniformly distributed over the desk both with the blinds up and down. Light levels under the light pipe are not affected by the blind's operation (mean 276cd/m^2, standard deviation of 18.5cd/m^2). The desk near the window shows higher luminance variations (300-920cd/m^2) when the blinds are up. The DGP is below 0.25 which is considered as imperceptible glare. However, the only case where DGP exceeds the 0.25 threshold (perceptible glare), is the area next to the window when the blinds are up. Luminance levels over the window area reach higher values with a mean 4,600cd/m^2 compared to the more uniform and lower luminance levels under the light pipe output (mean 800cd/m^2). The lighting conditions under the light pipe are visually more comfortable for occupants located at farther distances from the window wall.

4. Conclusions

The light pipe presented in this paper is an effective system that can provide healthy full-spectrum lighting in South-facing deep floor plan spaces for more than 9 hours under clear and partly cloudy sky conditions. The light pipe introduces consistently throughout the year illuminance levels between 300-2,500lux at 9m from the window wall. Exposing building occupants to bright light (>1,000lux) will help them regulate the timing of their circadian rhythms, which has a direct effect on sleep patterns, alertness and performance. The light pipe is a building component designed to meet not only visual needs and reduced energy consumption, but to increase the circadian light exposures in deep-floor plan buildings.

WORKSHOPS

WS1

WORKSHOP - INTERIOR LIGHTING DESIGN: METRICS AND ETHODS

Convener:
Thorns, P.
Zumtobel, County Durham, UNITED KINGDOM
Peter.Thorns@zumtobelgroup.com

Abstract

1. Motivation, specific objective

The lighting industry, and lighting design in particular, uses a well-established set of metrics and methods when designing lighting installations. These have become coded into standards and regulations, providing established benchmarks for both measurement and design. However whilst these have proven useful and have produced many good designs, they may not be the best solution for new technologies, energy efficiency and sustainability requirements, and with the increased understanding of both visual and biological impacts of light.

There is a need to reassess our use of common metrics and methods, and the possible suitability of proposed new metrics and methods, based upon current knowledge. It is important that any new system for design ensures that;

- Criteria and methods exist or can be developed.
- Criteria are calculable in design and measurable/verifiable in the field after installation.
- Criteria and methods produce outcomes that preserve or enhance lighting quality whilst being energy efficient and sustainable.
- New criteria and methods can co-exist with existing criteria to allow a managed change within standards and regulations, and are accepted by the design community, the value chain of developers / building owners etc., and by regulators/policy-makers.
- Criteria and methods are easy to understand and use.

This review should cover all metrics used within design and should also consider whether any additional metrics would be beneficial.

Methods

This will be in the form of a workshop to be held during the CIE 2023 Quadrennial session, with 3 small presentations to set the scene, followed by a mediated open discussion.

3. Results

Output from the workshop to be fed as input into CIE research strategy and/or Divisional work plan.

4. Conclusions

Not applicable until after the workshop.

WS2

CAN CONE FUNDAMENTALS BE USED IN EVERYDAY PHOTOMETRY?

Convener:
Bergen, A.S.J.[1]
[1] Photometric Solutions International, Melbourne, Australia
tonyb@photometricsolutions.com

Abstract

Since its beginning, colorimetry and photometry were directly related through the CIE colour-matching function $\bar{y}(\lambda)$ of the CIE 1931 standard colorimetric system which was set to be identical with the spectral luminous efficiency function for photopic vision, $V(\lambda)$. It is also well known that $V(\lambda)$ is not a perfect match to human vision and in particular it underestimates the visual response in the blue region. The physiology-based function, known as the cone-fundamental-based spectral luminous efficiency function, $V_F(\lambda)$, is defined in CIE publication CIE 170-2:2015, and again relates photometry to modern (i.e. cone-fundamental-based) colorimetry.

But switching to photometry based on cone fundamentals would have consequences including:

- The possible need to replace photometers with new devices that are either matched to the $V_F(\lambda)$ function instead of $V(\lambda)$, or which directly take spectrally resolved measurements and derive luminous quantities through software integration.
- The possible need for the definition of a new defining constant $K_{cd,F}$ for cone-fundamental-based photometry, the intention of which is to reduce the impacts of a change in photometrical scales.
- The replacement or supplementation of the existing colour-matching functions used in colorimetry with new functions based on cone fundamentals, including the possible need to replace tristimulus colorimeters with new devices that are matched to the new functions instead of the existing colour-matching functions and to update software or firmware for instruments which directly take spectrally resolved measurements and derive colorimetric quantities through software integration.
- The corresponding effects on scotopic photometry (including the quantity “S/P ratio” used to characterise sources) and mesopic photometry.

This workshop will feature three short presentations to introduce the topic, followed by a panel discussion with interaction from the audience to explore the implications of moving towards cone-fundamental-based photometry. The introductory presentations will be as follows:

1. Dr Lorne Whitehead (CA) – Introduction to cone fundamentals and the $V_F(\lambda)$ function;
2. Yoshi Ohno (US) – Viewpoint from CCPR and traceability;
3. Peter Blattner (CH) – Ideas for practical implementation of cone fundamental-based photometry.

WS3

LIGHTING EDUCATION: METHODS, APPROACHES AND EXPERIENCES

Convener:
Hao, L.
Tongji University, Shanghai, CHINA
haoluoxi@tongji.edu.cn

Abstract

1. Motivation, specific objective

The workshop targets to strengthen the influence of CIE on education and improve the collaborations among universities on the CIE platform. It aims to attract educators, researchers, and students from universities all over the world on participate and follow the CIE academic activities, and promote professional training in the lighting industry, establishing the connection between academia and industry on lighting.

2. Methods

The workshop will take 90 minutes, including a 5-minute introduction, a 30-minute invited speech session, a 50-minute open discussion session, and a 5-minute conclusion session. The location and time of the workshop will follow the arrangement of the 30th quadrennial session of the CIE. Three speakers will be invited from different fields for a 10-minute presentation, respectively, sharing their experience in academic research and profession training on lighting. During the discussion session, a list of topics will be discussed on the role and future work of CIE Education, understanding attendants' needs for CIE Education and collecting ideas & advices from the audience. Finally, the key points collected will be summarized in the conclusion session.

3. Topics

The following topics will be proposed for the 50-minute discussion:

a. What role can CIE play in the lighting education for professionals?

b. What are the expectations towards CIE in terms of academic education (access to publications, conferences, services, etc.)?

c. What CIE resources would be useful for the academic learning?

d. What supporting programs from CIE would be useful to encourage the work of young scientist and scholars?

e. How can CIE further support the continuing education of lighting professionals, including support to the education providers?

f. How to carry out the international certification of professional education?

g. What criteria could be set to indicate the level of knowledge, understanding, application and further dissemination on CIE lighting topics?

4. Conclusions

Above all, the workshop is proposed to raise the interest of attendants on CIE Education and understand the needs of academic scholars and industrial professionals from various aeras on CIE, collecting their ideas and advices to pre-plan the future work of CIE Education.

WS4

WORKSHOP – LOOKING AHEAD: LIGHTING FOR PREPAREDNESS

Conveners:
Fotios, S.
University of Sheffield, Sheffield, UK
Steve.fotios@sheffield.ac.uk

Veitch, J. A.
National Research Council of Canada, Ottawa, CANADA
Jennifer.Veitch@nrc-cnrc.gc.ca

Abstract

1. Motivation, specific objective

As a community associated with the research, design, application and operation of lighting, are we prepared for unusual or extreme events? At a micro scale, the level of individual buildings, then the answer is broadly yes. Emergency lighting is installed in many buildings to support occupant safety and egress in the event that a failure in electricity supply means there is no interior lighting. Emergency lighting has been the focus of research to establish what lighting qualities are needed, it has been the focus of life safety regulations, product design and installation, and is the ongoing focus of maintenance.

This workshop aims to initiate discussion about the macro scale by raising questions about the degree to which lighting is prepared for unexpected major events. In recent years, several events have occurred which placed large sections of society into crisis situations. The CIE needs to give guidance on how to governments, organizations, and individuals can plan ahead so that their lighting needs are met in times of unexpected circumstances.

One such major event was the Covid-19 pandemic. Here lighting has a direct role, with UV offering one means of infection control, and CIE responded by issuing a position statement to describe what should and should not be done with UV lighting (*Position Statement on the Use of Ultraviolet (UV) Radiation to Manage the Risk of COVID-19 Transmission*; available at cie.co.at/publications). Further discussion might be needed to consider how the CIE can support the world in having lighting that is ready for the next pandemic, and perhaps even to limit its effects.

In February 2023, a series of massive earthquakes hit Syria and Turkey, causing the collapse of many buildings. The immediate response to such an event is the search for survivors: a subsequent response is the provision of temporary accommodation for large numbers of displaced survivors. Preparation for this is unknown. For example, are there stockpiles of portable lighting to support the search for survivors? Are there suitable lighting systems ready for immediate use in temporary accommodation?

In addition to the immediate reaction, there may be a need to plan ahead for longer term responses. Some macro level events may cause disruption to the energy supply, either by increased costs or reduced availability: rather than switching off the road lighting in a city, CIE guidance might instead promote lower light levels, or the use of control systems to concentrate lighting on key transport routes so that the benefit of crash reduction is not entirely lost. There may be a need to plan for disruption to industry (and hence to national economies), requiring reconfiguration or repurposing of industrial and commercial spaces, requiring backup lighting systems in the same way that emergency lighting is installed for disruption to power supplies.

These are examples of circumstances for which preparations might be made, but there may be others. How the lighting community can assist in preparedness is a new topic to many of us.

2. Methods

This will be a workshop with a number of short presentations to set the scene, followed by a mediated open discussion.

3. Results

Output from the workshop to be fed as input into CIE Research Strategy and/or Divisional work plans.

4. Conclusions

The workshop will be considered successful if it leads participants to think about the preparedness of lighting.

WS5

METRICS FOR THE DESIGN AND IMPLEMENTATION OF ROAD LIGHTING

Convener:
Onaygil, S.
Istanbul Technical University, Energy Institute, Istanbul, TURKIYE
onaygil@itu.edu.tr

Abstract

1. Motivation, specific objective

Road lighting installations are designed to meet the quality criteria stated in national/international standards and recommendations such as CIE-115:2010. The main purpose of road lighting is to ensure that road users can travel safely and comfortably: it is therefore expected that the quality criteria are optimised to meet those needs, both at the time of installation and during the lifetime of the installation.

There are however many uncertainties in the current quality criteria.

- It is not known whether the existing quality criteria are sufficient and optimal to provide the necessary safety and comfort. One reason for this is that the empirical basis for the quantitative criteria is unknown.

- Values measured in the field after installation may not match the standard used as the target for design; the reason for discrepancy is unknown.

- It is not knowing the extent to which field measurements recorded at the point of installation are sufficient for their performance qualifications throughout the lifetime of the installation.

- Due to the emergency in energy supply, some public administrations are employing ad hoc changes in operation of road lighting: it is not known how this affects the safety of road users.

- The extent to which adaptive lighting applications are a solution in terms of safety and energy emergency is not yet known.

The direct aim of this workshop is to discuss the uncertainties of current road lighting guidance and define what needs to be done next. The long term aim is to produce a revision to CIE 115.

2. Methods

This will be a 90-minute workshop with three presentations to stimulate discussion. The workshop program is shown below.

Presentation 1: “Adequacy of current road lighting recommendations in real field applications” (10 minutes) *speaker proposal: Steve Fotios*

Presentation 2: “The differences between design and field measurements” (10 minutes) *speaker proposal: Valerie Muzet*

Discussion 1: The relevance of current standards and further research needed (40 minutes)

Presentation 3: “Examination of current practices and solution proposals due to energy emergency” (10 minutes) *speaker proposal: Dionyz Gasparovsky*

Discussion 2: What to do next (20 minutes)

3. Results

– The need for additional research studies and technical report update, especially within the scope of CIE 115

- Inconsistencies between design and implementation results for reasons such as estimation of road pavement properties in accordance with real conditions, difference of LED luminaire photometry compared to conventional luminaires
- Safety problems caused by turning off road lighting
- Suggestions for solutions that will not create a safety problem in the face of the energy crisis and therefore the desire to save energy

4. Conclusions

At the end of the workshop, it is aimed to define the deficiencies in providing road lighting in accordance with the real conditions, the research and technical committee studies that are currently being worked on or to be planned, and to determine a road map.