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SELECTED METROLOGY PROBLEMS IMPLIED BY THE APPLICATION OF LED TECHNOLOGY IN LIGHTING

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Abstract. *High power LEDs replace traditional light sources in all possible lighting applications, causing significant problems in assessing the quality of lighting. This issue is not limited only to the construction aspects of the measuring equipment, but also has a cognitive dimension. The article presents an overview of the current state of knowledge on color rendering and evaluation of discomfort glare in relation to the widespread use of LEDs in lighting. Some selected parameters developed copyright sources with LED sets. Basic limitations in UGR measurement were indicated.*

Keywords: light emitting diodes, measurement, lighting technology

WYBRANE PROBLEMY METROLOGICZNE IMPLIKOWANE STOSOWANIEM TECHNOLOGII LED W OŚWIETLENIU

Streszczenie. *Diody świecące dużej mocy zastępują klasyczne źródła światła właściwie we wszystkich możliwych aplikacjach oświetleniowych, co powoduje znaczne problemy w ocenie jakości oświetlenia. Zagadnienie to nie sprowadza się wyłącznie do aspektów konstrukcyjnych aparatury pomiarowej, lecz także ma wymiar poznawczy. W artykule przedstawiono przegląd aktualnego stanu wiedzy na temat oddawania barw oraz oceny olśnienia przykrego w odniesieniu do powszechnego stosowania diod LED w oświetleniu. Omówiono wybrane parametry opracowywanych autorskich źródeł z zestawami LED. Wskazano podstawowe ograniczenia w technice pomiarów UGR.*

Słowa kluczowe: diody elektroluminescencyjne, pomiary, technika świetlna

Introduction

Recent years have brought a rapid growth of the importance of light-emitting diodes (LEDs) in the widely understood light technology (lighting technology). High power LEDs replace traditional light sources in almost every possible lighting application – from the interior and exterior illumination [26], through medical applications [4] to the attempts of creating LED-based reference sources. Rationale for such actions is - first of all - extremely high luminous efficacy of LEDs, that allows to achieve significant savings of energy consumed, and sometimes additional benefits arising from the possibility of controlling the optical properties of such sources. However, in case of this kind of light efficacy not always comes together with quality defined in a way we understand it nowadays.

Until now there is no reliable research really to resolve the influence of LEDs on the man and his health and even reports on its harmfulness appeared [2]. It is known that using lighting based on light-emitting diodes the human circadian rhythm can be affected, which may also entail some health effects. It is also known that some of currently used measurement techniques [23, 28] and the criteria considered to be appropriate in the design of lighting [33] are mostly not reliable when applied to light-emitting diodes [27, 32]. Research groups around the world have consistently shown that the very rapid spread of LED technology in lighting is not correlated with adequately rapid development of measurement techniques, so there are a number of significant problems arising not only from the lack of measuring devices, but also the lack of appropriate indicators reflecting the real impact of lighting conditions, in which the visual work is performed and the influence on people. Discomfort glare and flicker are particularly important determinants of visual comfort. These are the two main phenomena accompanying the process of vision which impact on human health has been proven for the older generation sources [14] and measurements which are currently difficult, even impossible due to the lack on the cognitive level. Additionally, also applicable (normative) definition of the light quality indicator in the context of the proper color rendering is an important issue in the correct evaluation of the quality LED sources.

1. Color rendering and light emitting diodes

Color is one of the key attributes of objects. It is rooted in human perception that originates from the structure of our cornea photoreceptors and their spectral sensitivity to light. It results with the system of color matching functions (Fig. 1) that are at the basis of the concept of color description.

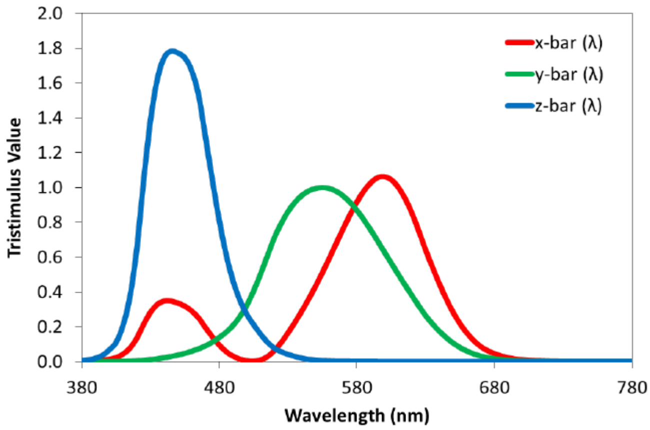


Fig. 1. XYZ color matching functions according to CIE system [26]

Appearance of color of an object is a result of its spectral reflectance, the way that human eye reacts and spectral composition of light used to illuminate the object. Considering only the last factor it is obvious that when various spectral power distributions (SPDs) are used, the appearance of the same object will be different. This problem becomes essential when color of the object is the main criterion of its evaluation, for example during the operation when the condition of the tissues is evaluated.

Light sources are characterized in terms of the color of light emitted and color rendering. The first feature is described by correlated color temperature CCT, coordinates on the chromaticity diagram (3 systems are possible), distance from the Planckian locus on the chromaticity diagram Duv and MacAdam ellipses (that were converted to binning parameters in case of LEDs). Color rendering evaluation is conducted according to the the general color rendering index (CRI *Ra*) established by the Commission Internationale de l´Eclairage (CIE) and accepted by national standardization committees as the valid one. Limitations of this method are widely known [35, 40]. They are clearly visible when applied to light sources with highly-structured SPD (with sharp changes in slope, spikes, discontinuities, or some regions of smoothness and others that are spiky). The main problem is that it is very easy to obtain very high value of rendering indexes according to this system by specific construction of the SPD, even for light that in fact has a poor quality in terms of color rendering.

A good example of such light source is LED. Nevertheless, *Ra* has been used continuously for over 50 years and in practice of general illumination is still in use, also applied to LEDs.

CIE technical committee (TC1-62 Color Rendering of White LED Light Sources) established in 2002, concluded that *Ra* cannot even correctly rank-order the color-rendering ability of light sources when LEDs are included [13], the committee decided that it is necessary to recommend an alternative measure. Since that time many research groups contributed with their proposals of new methods of evaluation of light quality in terms of color rendering.

The review of proposed measures of color rendition is collected in Table 1. It was ordered with consideration of the timeline of evolution of these indexes from the very beginning till recent years, when the research was visibly intensified.

Table 1. Evolution of color rendition measures [6, 9, 10, 16, 20, 29, 30, 31, 34, 36, 38, 39]

Measure (year) (Abbreviation)	Short description	Measure (year) (Abbreviation)	Short description
Former CIE Test Color Method (1965) (*Ra*)	Based on a different chromatic adaptation model	Gamut Area Index (2004) (*GAI*)	The gamut area for an equal-energy reference spectrum is assigned a GAI of 100. Other illuminants are normalized to this value, yielding either higher or lower values of GAI. The practical range is about 10 – 130. Suggested to be used in conjunction with Ra
Flattery Index (1967) (*Rf*)	Ten test-color samples considered with unequal weighting. Reference illuminant at the same CCT. The maximum value is 100 and the reference has a value of 90.	Full Spectrum Color Index (2004) (*FSCI*)	Informs how much a light source's SPD deviates from an equal-energy spectrum. Equal energy reference receives a score of 100 and warm white fluorescent receives a score of 50. Negative values are set to zero. It is intended to be a measure of fidelity. Linear transformation from the Full-Spectrum Index (FSI).
Color Discrimination Index (1972) (*CDI*)	Higher CDI is associated with a larger gamut in the CIE 1960 UCS chromaticity diagram. The gamut is normalized to 100 based on CIE illuminant C. The practical range is 10-130.	Feeling of Contrast Index: CIE CAT94 (2007) (*FCI94*)	Derived from a transformation of gamut area formed by a four-color combination of red, green, blue, and yellow in CIELAB. D65 always employed. Corresponds to a ratio of D65 illumination to the test illuminant illumination for equal "feeling of contrast". For D65 FCI94=100, higher and lower values are possible; the practical range is about 20 – 200.
CIE Test Colour Method (1974) (*CRI, Ra*)	Represents the mean color shift of eight test color samples under an illuminant in comparison to a reference illuminant of the same CCT in the CIE 1960 UCS. The maximum value is 100 and the reference always has a value of 100, irrespective of CCT. Negative values are possible.	Feeling of Contrast Index: CIE CAM02 (2007) (*FCI02*)	Conceptually similar to FCI94, but computed using the CIECAM02 color appearance model and CIECAT02 chromatic adaptation formulae. D65 has a value of 100; the practical range is about 20 – 150.
Special Index 9 of CIE Test Colour Method (1974) (*R9*)	Characterizes the resultant color shift of saturated red. The maximum value is 100 and the value of R9 for the reference illuminant is always 100, irrespective of CCT. Negative values are possible.	Color Preference Scale of CQS version 7.5 (2009) (*QP*)	Scaled from 0 – 100 and so that 12 reference fluorescent lamp spectra have equivalent values of Qp and Ra.
Color Preference Index (1974) (*CPI*)	Array of test-color samples is used. Equally weights the 8 test-colors. Has a reference illuminant The maximum value is 156 and the reference has a value of 100.	Rank-Order Color Rendering Index (2010) (*RCRI*)	Computed using CIE CAM02 formulae and 17 test-color samples. Scale is defined with reference to a predicted number of excellent and good ratings of the test-sample colors. Range of 0 – 100.
Farnsworth-Munsell Gamut (1977) (*FMG*)	The area enclosed by a line joining the positions of all 85 testcolor samples of the Farnsworth-Munsell 100 Hue Test computed in the CIE 1960 UCS. Index normalized to 100, based on CIE illuminant C. Values greater than 100 possible.	Memory Color Rendering Index (2010) (*MCRI*)	Based on observers' memory of the preferred color of 10 familiar objects. No reference illuminant; the reference is color memory. Tristimulus values for the objects are transformed to corresponding colors under D65 illumination using CIECAT02and then transformed to the IPT color space has a range of 0 – 100. The result affected by the degree of adaptation and illuminance.
Color Rendering Capacity (1984) (*CRC84*)	Based on the number of object colors that an illuminant can theoretically render. Based on computation in the CIE 1960 (u, v, Y) space. Theoretical range of 0.0 – 1.0, usually 0.15 – 0.40.	Color Fidelity Scale of CQS version 9.0c (2012) (*Qf*)	Computed the same way as Qa except the saturation factor is excluded. Similar function to Ra. Scaled from 0 – 100 and so that 12 reference fluorescent lamp spectra have equivalent values of Qf and Ra.
Pointer's Index (1986) (*PI*)	Based on 16 sub-indices related to hue, lightness and chroma for red, yellow, green and blue. The sub-indices can be combined to produce an overall index. 18 test color samples in the Macbeth color checker. Any illuminant can be employed as the reference. The scale is 0 – 100.	CRI2012 Colour Rendering Index (2012) (*Ra2012, nCRI, Ra12*)	Ra2012 is a scale of 0 – 100 that maintains a similar computational structure as Ra while employing fundamental improvements: computations are done using CIE CAM02-UCS, an (imaginary) set of test-color samples was developed and optimized, and color differences are combined with a root mean square. Like Qa, it is scaled so that 12 reference fluorescent lamp spectra have equivalent values of Ra2012 and Ra. Like Qa, it also employs the same reference illuminants as Ra.
Color Rendering Capacity (1993) (*CRC93*)	Index calculated in CIELUV as a ratio of the color solid volume obtained under a test illuminant to that obtained with an equal-energy spectrum. The minimum value is 0.0 and the maximum value can exceed 1.0.	Color Quality Scale version 9.0c (2012) (*CQS, Qa*)	Scale of 0 – 100 that maintains a similar computational structure as Ra while employing fundamental improvements: a better chromatic adaptation model (CMCCAT2000), 15 saturated test-color samples, illuminants are not penalized for increases in chroma, computations are performed in the CIELAB color space, color differences are combined with a root mean square, and sources with extremely low CCTs are penalized because they have smaller gamut areas. It is scaled so that 12 reference fluorescent lamp spectra have equivalent values of Qa and Ra. Like Ra, all CQS indices (i.e., Qa, Qf, Qp, Qg) are based on comparison to a reference illuminant at the same CCT. Note that the reference cited is for an earlier version of CQS that employed a somewhat different formulation that described in this paragraph and employed in this paper (e.g., seven of the 15 test-color samples have been changed, the CCT factor was removed, and Qg in v9.0 is scaled based on a reference illuminant with equal CCT.
Cone Surface Area (1997) (*CSA*)	The base of a cone formed using the gamut of the eight CRI test-color samples within the CIE 1976 UCS diagram (u', v') and the height is determined from the chromaticity of the test illuminant. Combines a measure of gamut with source chromaticity. Not normalized to any reference illuminant.	Relative Gamut Area Scale of CQS version 9.0c (2012) (*Qg*)	Computed as relative gamut area formed by the (a*, b*) coordinates of the 15 test-color samples in CIELAB normalized by the gamut area of a reference illuminant at the same CCT and multiplied by 100. Scaling is different from Qa, Qf, and Qp and can be greater than 100. Qg does not employ a chromatic adaptation transform.

Comparative analysis of all indexes conducted in [21] concludes that the newer indices are not remarkably different from the older ones. Many of the newer measures have stronger theoretical foundation, for example by employing different sets of test-color samples, improved CIE color appearance models, chromatic adaptation models or color spaces. Nevertheless, when the result of calculations is a single number, frequently on a scale from 0 to 100, these improved computational approaches yield results that are highly similar to longstanding measures that were based on essential models.

In practical applications still the *Ra* method is used and only 8 samples of 14 (Fig. 2) are taken into account as this solution is mentioned in the illumination standard PN-EN 12464-1. For given sample, the color under the tested source is compared to the one it would have with a reference light. The R_a is given by the calculation of the color differences. It decreases when the differences increase. In principle, the reference light needs to have the same color temperature as the tested source and the best possible color rendering. The Planck's radiator is chosen below the color temperature of 5000 Kelvins and the appropriate daylight above 5000 Kelvins. The calculation of the difference ΔE_i between the color of the sample under the tested source and the adjusted color under the reference light is done. Each color difference corresponding to the sample (*i*) is used to calculate the R_i

$$R_i = 100 - 4{,}6 \cdot \Delta E_i \quad (1)$$

The average CRI *Ra* obtained by averaging the indexes (R_i) for all the eight samples is

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i \quad (2)$$

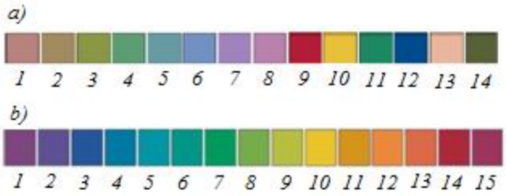
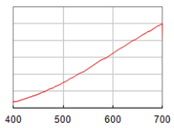
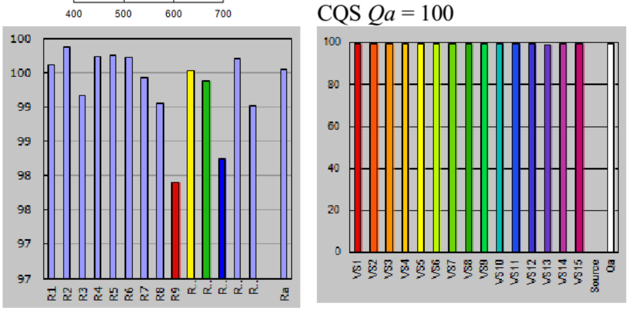


Fig. 2. Samples used in a) CRI Ra Scale, b) Color Quality Scale (CQS) (sample number increasing from left to right)

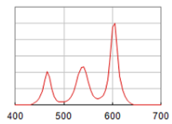
a)



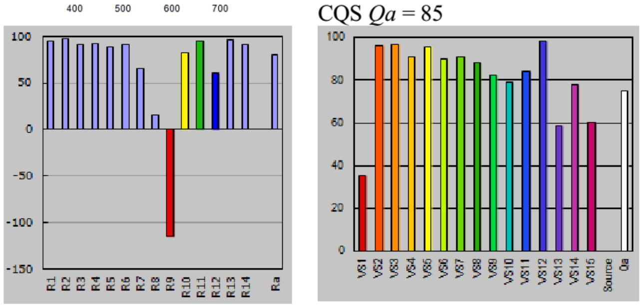
Incadescent, CCT=2860K
(close to Illuminant A)
CRI *Ra* = 100
R_9 = 98
CQS *Qa* = 100



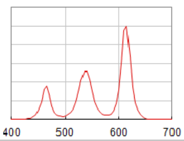
b)



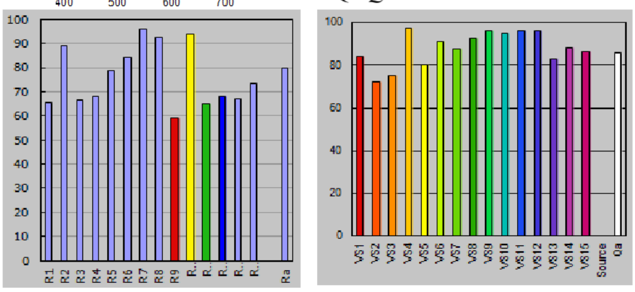
LED RGB, CCT=3300K
(466nm, 538 nm, 603 nm)
CRI *Ra* = 80
R_9 = -114
CQS *Qa* = 85



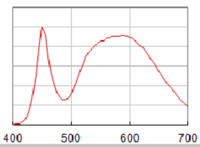
c)



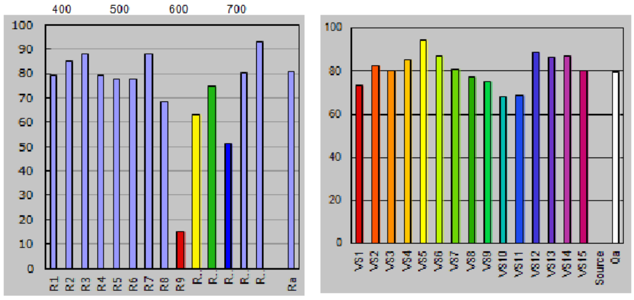
LED RGB, CCT=3300K
(466nm, 538 nm, 613 nm)
CRI *Ra* = 80
R_9 = -114
CQS *Qa* = 85



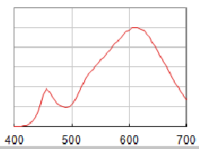
d)



LED CREE, CCT=4100K
CRI *Ra* = 81
R_9 = 15
CQS *Qa* = 80



e)



LED CREE, CCT=2853K
CRI *Ra* = 84
R_9 = 26
CQS *Qa* = 85

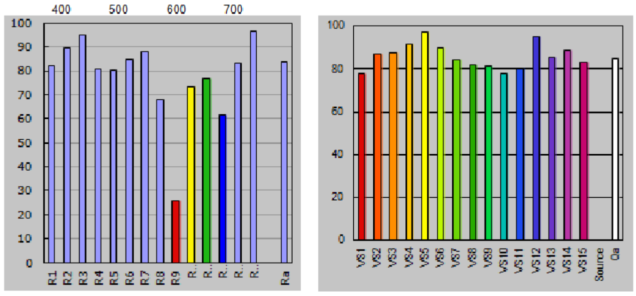


Fig. 3. Comparison of calculations of CRI Ra and CQS Qa for exemplary light sources

One of the leading color research groups, representing National Institute of Standards and Technology (NIST), showed [16] that light sources can perform poorly with saturated test-color samples even when they perform well with the 8 desaturated test-color samples employed in the computation of *Ra* and Gammut Area Index GAI (Fig. 2). Comparing the calculated color rendering index and the deviation calculations in CIELAB to visual observations, the CRI was shown to inaccurately predict the visual observation when exposed by LEDs. The conclusion appeared that the choice of test samples is often critical for modeling the color rendering. Some can obtain excellent values, whereas others obtain poor indexes. Following this work, the authors have developed a single index called Color Quality Scale *Qa* (CQS *Qa*), which reflects the impression of an observer more accurately than the CRI [17]. The scale is adjusted so that the average of CIE source F1 through F12 (CIE 15.2) is the same as that of CRI *Ra*. It involves different set of 15 saturated color samples with carefully balanced tonality (Fig. 2) and is calculated as root mean square of all factors obtained for each sample. Examples of calculations results for selected SPDs are presented in figure 3. They were calculated according to NIST CQS version 9.0.3. (2013) [29].

In the beginning of 2016 CIE has introduced the report that presents a new method to evaluate the strength of the relationship between visually-perceived color differences in a given set of color pairs and their corresponding predictions made by a color-difference formula. This method is based on the Standardized Residual Sum of Squares (STRESS) index and tests if two color-difference formulae are or are not statistically significantly different. In recent years significant advances have been made in the field of color-difference evaluation using different visual datasets currently available. The results achieved from the STRESS index indicate, that it is not possible to recommend a more uniform color space with a Euclidean color-difference formula that is statistically significantly better than CIEDE2000 [15]. Nevertheless until the industrial standards are changed, the mismatch between application requirements and the state of art in the area of color rendition will be distant, which may cause various problems originating from the effects of light on human.

1.1. Examples of applications of tunable sources

Daylight is an outstanding light that renders colors naturally and with high fidelity. This is the reason why tunable, multi-emitter light sources are one of the directions in current research in applications where perfect color rendering is necessary. Multi-emitter LED systems are more and more often used as semiconductor models of the illuminants, however their great practical potential is still to be used, especially for the construction of energy-efficient systems allowing to stimulate alertness of the worker or building tunable sources for use in special illuminating systems eg. medical [4]. At the Faculty of Electrical Engineering, Bialystok University of Technology (Politechnika Białostocka, Wydział Elektryczny) two projects focused on applications of LEDs in order to improve conditions of visual work are provided. Although their main aims are joint – to built tunable sources based on LEDs that allow to follow different correlated color temperatures with high rendition indexes obeying current requirements – applications of those sources will be different. For this reason different research and engineering problems occur.

The aim of one of the projects is to build a modular luminaire for general illumination. The task includes both the selection of emitters for the emitted spectrum forming within assumed CCT range with high quality color rendering maintained and the lumen output stability, as well as spatial aspects (glare control by the appropriate formation of photometric solid). Slightly different issues arise when dedicated to medical applications lighting are taken into account, in case of the second project the endoscope illuminating system. During medical procedure it is very important to perceive colors correctly, therefore spectral characteristics and color rendering are the priority in the design of such light source. Practice shows that in this case, the luminous flux is of secondary importance – even a single white LED can provide the illumination of the tissue sufficient to observe. Thus, the key issue is to choose and control the set of LEDs that together can create stable over time source with very good colorimetric properties. Radiation from such a set should be mixed and brought to the vicinity of the examined tissue – optical fibers are usually used for this purpose.

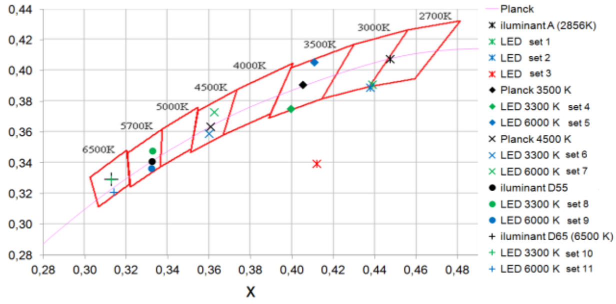


Fig.4. Chromaticity diagram (x, y) of reference sources (illuminants) and multi-emitter sets of LEDs in comparison to the binning parameters of white LEDs according to ANSI C78.377-2011 [19]

Selection of LEDs for both applications has been carried out on the basis of available literature models of optical radiation emission for LEDs. Then the sets of LEDs were tested to prepare their real models that were the basis for SPDs modeling. Exemplary results of calculations are presented on the chromaticity diagram of obtained spectra based on one set of LEDs composed of 13 emitters (Fig. 4). It must be underlined, that for all sets very high CRI *Ra* (more than 90) values were obtained and R_9 was over 95.

The total spectral characteristics of sources based on LEDs can be modified depending on the lighting requirements by turning on or off selected emitters and control the operation conditions of each element. The advantage of this solution is its simplicity, low power consumption, lack of ultraviolet and infrared radiation and especially the ability to influence the correlated color temperature of the source while maintaining high color rendering parameters.

2. Glare and light emitting diodes

Another significant problem in modern metrology of lighting are measurements of luminance, luminance distribution and associated with them discomfort glare, when small sources appear within the field of view. Commonly used method to evaluate glare is to calculate the *UGR* factor according to the CIE recommendation [11]:

$$UGR = 8 \cdot \log\left(\frac{0{,}25}{L_t}\sum\frac{L^2\omega}{p^2}\right) \tag{3}$$

where L_t is a background luminance within the observer's field of view, L is luminance of the glares source in the direction of the observer, ω is the angular size of the glare source and p is the Guth position index. This method is also normative method in Poland mentioned in [33]. Another formulas are also known. For example in case of small sources - with the apparent surface area of not more than 0,005 m^2 and located at least 5° away from the line of sight, glare caused by the source is determined by its luminous intensity I, so the following relationship can be written[12]:

$$\frac{L^2\omega}{p^2} = 200 \cdot \frac{I^2}{r^2 \cdot p^2}\,. \tag{4}$$

In this formula it was assumed that the luminance of the light source should be expressed by the ratio of luminous intensity of the source and its apparent luminous surface (both in reference to the location of the observer' eyes). However, this size limitation does not solve the problem of assessing glare from the LED sources. In this case the situation is more complex because - apart from extremely small light sources – there is a problem of the luminance non-uniformity of the luminaire, which can be composed of a large number of LEDs arranged in different layouts.

Both relations mentioned above were obtained from many experiments with big groups of volunteers, but not using LEDs as glare sources. Consequently it is not obvious that glare caused by solid state light sources can be described in the same way. These problems were recognized together with the rapid increase of LEDs' in everyday lighting applications. Group of researchers that are authors of the CIE publication [14] indicate glare caused by LEDs as one of the most important investigation directions in current lighting technology. There have already been some projects focused on some parts of this problem [14]. Their conclusions prove that:

- for the same average value of the *UGR* index derived from sources located on the line of sight from the glare source of non-uniform distribution appears to be greater than for a uniform stimulus [37],
- intensity of glare decreases in both cases, the farther upwards the line of sight [25].

The question of the need for new indicators of glare caused by non-uniform luminance distributions is discussed in [8], which authors found that all current models are inadequate to assess the glare from these sources. Other studies prove that the assessment glare of complex scenes (with both small or large sources) may require fundamental changes in the development of illumination models [18]. Apart from spatial arrangement of sources also the spectral considerations are poorly recognized. Deep, careful investigation of influence of the color and spectral composition of the glare source, especially now, when different SPDs of LEDs are available, should be carried out.

Considering above problems it can be concluded, that currently legally formalized glare evaluation method is based on wrong premises and should be made the subject of extensive, substantive discussion.

2.1. Selected problems of luminance distribution and glare measurements with light emitting diodes

Luminance meters are constructed according to the CIE definitions and requirements. For this reason measurement area in most cases is defined by angles 1°, 1/3° and sometimes even 0.1°, which gives the minimum measuring area to 0.4 mm diameter in the recently developed meters. However, operation of these meters is based on integration of light, so they give an average luminance of the area. In some cases this kind of measurement is enough, but there are many applications where precise information about luminance distribution is required, for example the above mentioned glare measurement. In this situation integrating detector is useless. *UGR* factor – as one of the parameters mentioned in the lighting standard defining quality of lighting system – although is known from many years, is still analyzed mostly during the design process. Practical verification of this parameter is conducted rarely. The main reason is low availability of measuring devices – in fact only one company offers such meters and their price is very high, but research on method of measurement were and are conducted by several researchers, for example [3]. The construction of such meter is always based on the CMOS (or CCD) detector as in fact this meter should be a geometrically calibrated luminance meter.

Operation of the CMOS detector as a luminance distribution meter is based on the transmission of light reflected from or produced by the objects within the field of view. Assuming that the elementary area of the object which luminance is L_{ij} (measured from the position of the observer's eye) is imaged onto a single element of light-sensitive area S_{ij} of the matrix, the illuminance of the surface of this photoelement is

$$E_{ij} = \frac{\tau \cdot \Phi_{ij}}{S_{ij}} \tag{5}$$

where Φ_{ij} is the luminous flux incidenting the surface of the photoelement and τ is transmission coefficient of the optical system (lens, filters etc.). Luminous flux Φ_{ij} depends on the luminance (in the direction α) of the elementary area of the object $L_{\alpha ij}$, so if the illuminance E_{ij} is known, luminance of each part of the object imaged on the detector can be measured:

$$L_{\alpha ij} = \frac{\tau \cdot E_{ij}}{\omega_{ij} \cdot \cos \alpha_{ij}} \tag{6}$$

where ω_{ij} is a solid angle correlated with the single photoelement of the detector.

Single photoelement captures a certain amount of radiant power (correlated with the luminous flux by the luminous efficiency factor). This radiant power is dependent on the SPD of the object, aperture and focal length of the imaging lens, the construction of the detector (the fill factor, whether it is front- or back-illuminated etc.). Then, considering the quantum efficiency of the detector and its varying spectral sensitivity to different wavelengths of incident light, photons are converted to electrons and produce the output signal. As a result the correlation between the possibility of detection of certain amount of light incident from areas of various luminance can be calculated in reference to the size of the single photoelement. Correlation of these parameters exceeds the intended content of this article, but is the subject of current analysis. Nevertheless it is obvious, that there is an upper and lower energy limit when light detection is considered. In short the upper limit is connected with the capacity of single potential well of the matrix and the lower limit comes from the size of the single photoelement together with signal to noise ratio (SNR).

The size of the single photoelement has to be taken into account also when resolution of the camera-based meter is analyzed (together with the parameters of the lens). In case of luminance distribution or glare measurements the human anatomy has to be taken into account as it defines the expected values. The resolution of the human eye is various depending on the position on the cornea – it starts from 0.5 min arc for a majority of the population [7] which should be considered when such meter is constructed, especially if precise luminance distribution measurements of small objects are required. Such necessity appeared together with LEDs as their dimensions are very small when compared to the traditional light sources, thus the solid angle ω, that encloses the light source, for the typical lens used with the luminance distribution meters is – for most real distances light source-eyes – below the limit allowing proper measurement of luminance distribution of such source. This problem didn't exist in fact till the moment when LEDs appeared in lighting. It can be stated that before the luminance distribution and glare measurements were widely understood and applied, a new challenge has grown.

3. Conclusions

In the paper some considerations of current problems in lighting metrology were presented. They show that it is appropriate to carry out the verification of existing normative criteria for assessing the lighting quality, their modification or introducing new indicators defining the conditions that must be fulfilled by lighting system so that it could be regarded as correct, but also safe for humans. While in case of color rendering index works are fairly advanced and in the near future attempts to replace CRI *Ra* index with another one can be expected, whereas in the case of mentioned in the article glare the problem is at the level of recognition and requires much research.

Considering problems mentioned in the paper it can be concluded, that two of four parameters mentioned in the standard for interior lighting, are currently based on the wrong premises and should be made the subject of extensive, substantive discussion. Flicker, which is a very important quality parameter of lighting system, in case of LEDs is unrecognized in terms of its influence on human beings, thus also in this area of light metrology new research issues have grown.

Color-difference formulas are currently used in many applications, for example automotive industry, printing, textiles, medical images, food and agriculture. It should be recognized that, with an average accuracy of around 65–75% [22], all modern color-difference formulas are unfortunately not very accurate in predicting perceived color differences. That is, modern color-difference formulas need improvements in order to be more reliable in automatic quality control and industrial applications. It is obvious that products, also lighting products, are designed according to evaluating metrics. In case of color rendering metrics that is still valid is based on CRI method although scientist and industry representatives are aware of its disadvantages. As inadequate metrics can lead to poor products changes in metrology legislation related to color rendition is only a matter of time.

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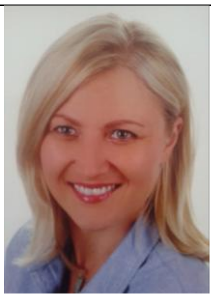

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