SDAR* Journal of Sustainable Design & Applied Research

Volume 5 | Issue 1 Article 6

2017

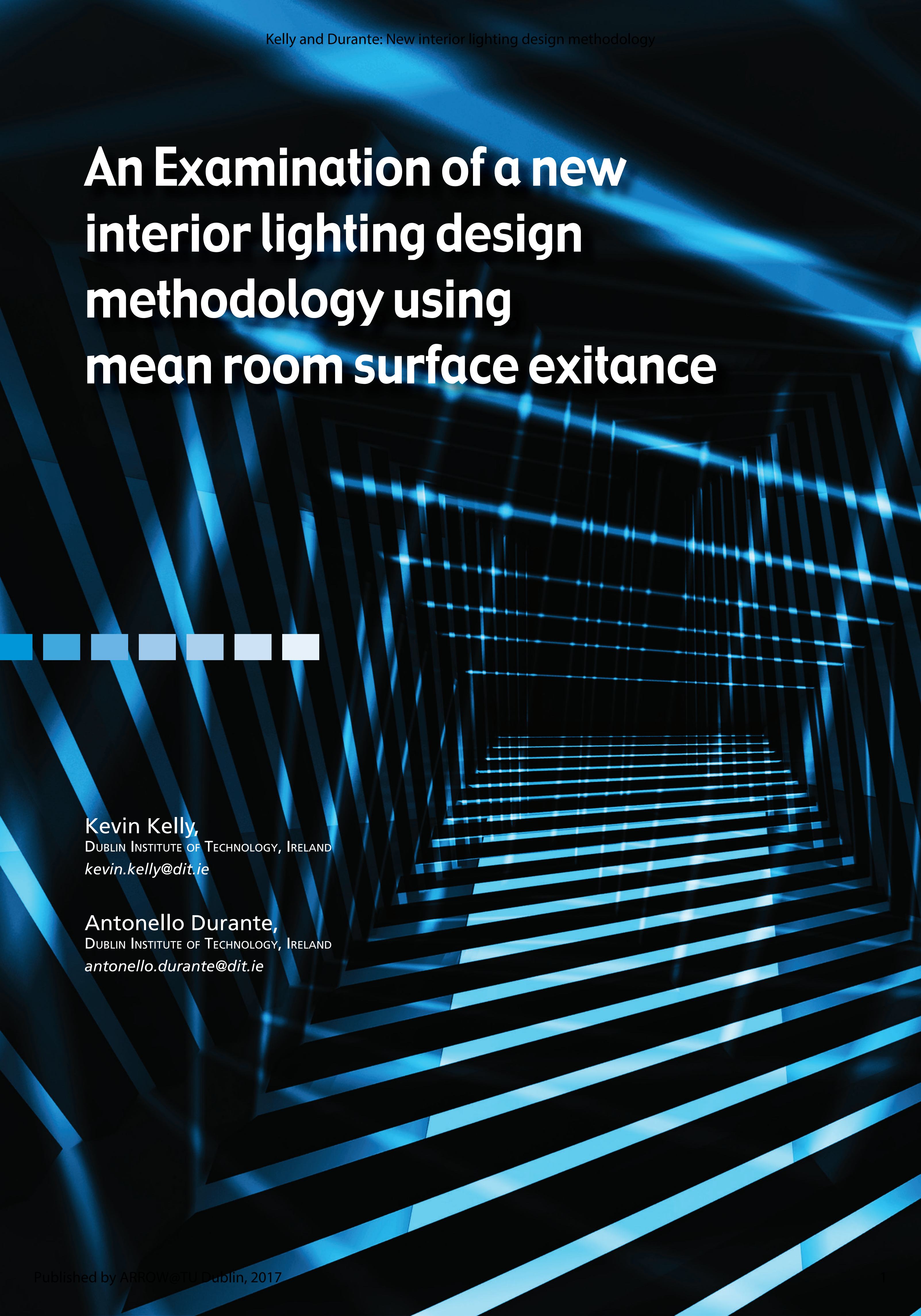
An Examination of a New Interior Lighting Design Methodology Using Mean Room Surface Exitance

Kevin Kelly
Technological University Dublin, kevin.kelly@tudublin.ie

Antonello Durante
Technological University Dublin, antonello.durante@tudublin.ie

Recommended Citation

Kelly, Kevin and Durante, Antonello (2017) "An Examination of a New Interior Lighting Design Methodology Using Mean Room Surface Exitance," *SDAR* Journal of Sustainable Design & Applied Research*: Vol. 5: Iss. 1, Article 6.
doi:https://doi.org/10.21427/D72F22
Available at: https://arrow.tudublin.ie/sdar/vol5/iss1/6



An Examination of a new interior lighting design methodology using mean room surface exitance

Kevin Kelly,
Dublin Institute of Technology, Ireland
kevin.kelly@dit.ie

Antonello Durante,
Dublin Institute of Technology, Ireland
antonello.durante@dit.ie

Abstract

This paper disseminates both new and previously-published findings to show how a whole new lighting design system can be easily implemented, whereby interior lighting is designed for appearance rather than visual performance alone. This paper presents the findings of multiple PhD research undertaken in the Dublin Institute of Technology that started in 2011 and continues.

This paper is presented for a building services engineering audience and emphasises why there is a need for change, what it is that is proposed, the implications for existing practice, the benefits of the new design methodology, and the challenges remaining before it can be fully adopted in practice.

Evidence is provided in this paper that MRSE is a better metric than horizontal illuminance in measuring people's perceived adequacy of illumination in a room. Proof of concept is evidenced with respect to ensuring software can be easily developed for design using MRSE and in measuring MRSE easily in installations using HDR imaging. Typical values of MRSE in existing installations are presented.

Keywords

New interior lighting design methodology, MRSE.

Glossary

MRSE *– Mean Room Surface Exitance*

IH *– llumination Hierarchy*

TAIR *– Target Ambient Iiluminance Ratio*

CIBSE *– Chartered Institution of Building Services Engineers*

SLL *– Society of Light and Lighting*

Lm/m² *– Lumen/square meter*

Cd/m² *– Candela/ square meter*

U_o *– Uniformity*

HDRi *– High dynamic range imaging*

1. Introduction

For nearly 100 years interior lighting has been designed in workplaces to enhance performance. Illuminance levels were designed for a working plane. In offices, this was mainly an imaginary horizontal plane taking in the entire area of a room at desk level. For many decades this was a valid, reliable and easily-understood methodology, hence its longevity.

This paper explains why there is a need to change existing lighting design practice from one using horizontal illuminance as the main design metric to one using a whole new methodology with new metrics called Mean Room Surface Exitance (MRSE) and Target Ambient Illumination Ratio (TAIR). MRSE is a metric invented by Cuttle[1] to measure perceived adequacy of illumination (PAI) and TAIR refers to the designed illumination hierarchy also devised by Cuttle[1]. The implications for existing practice are explained and the potential benefits/shortcomings of the new design methodology examined, along with an analysis of the challenges remaining before it can be fully adopted in lighting practice.

Modern offices and educational spaces have entirely different functions than envisaged by the researchers who originally developed the existing methodology based on horizontal illuminance. There is now widespread use of screen technology and more human interaction in modern workplaces. This, and the advent of much-improved LED technology[2], makes a new and improved lighting design methodology appropriate for such spaces, particularly as the same consulting engineers strive imaginatively towards near zero energy buildings in other design aspects.

Lighting design carried out within consultant engineering offices has changed little over many decades. Work plane illuminance E_h (usually the horizontal plane throughout the room) has remained the predominant central design metric throughout that time. The CIBSE/SLL Code for lighting[3] has been the source of information for designers in the UK and Ireland (and in many other countries) during that time. In Europe, EN 12464-1[4] applies for interior lighting, in the USA the Illuminating Engineering Society of North American (IESNA) apply similar standards and all of these look towards the International Commission on Illumination (CIE) for coordination of international standards for lighting.

The Society of Light and Lighting (SLL) is now part of CIBSE but, in its earlier form, it was known as the Illumination Engineering Society and Illumination Society of Great Britain. It has been setting standards for lighting for over 100 years and the SLL Code[3] is further supported by a Lighting Handbook[5] and 14 application guides[6], all published by SLL/CIBSE. All of the standards and Codes use horizontal illuminance as its main design criterion. Indeed, this has been seen by the industry as an appropriate and pragmatic method of designing lighting up to now.

However, the SLL Code[3] admits that conformance with the Code can only hope to eliminate bad lighting and ensure indifferent lighting. This allows people see things quickly and easily without visual discomfort. The focus is on the visual task and functionality of the lighting. This was appropriate at one time but a higher standard is

Figure 1a – Open plan office, Larkin Administration Building – Buffalo NY, 1930s – and 1b – Historic office and drawing office practice.

desirable nowadays to achieve good quality lighting. People in offices up to the 1980s, such as those in the in Figure 1, may well have required 500 lux on their desk and 750 lux on their drawing boards. Their visual task was entirely desk-based and visually challenging, especially if reading poor quality carbon copies and blueprints.

A typical engineer, designing office lighting or classroom lighting, will use the Code[3] and Guides[6] to focus on the required horizontal illuminance and ensure that the lighting selection does not cause excessive glare, while still providing acceptable colour performance. S/he will use the lamp with optimum performance, mainly LED nowadays, and give some consideration to background illuminance or luminance, and maybe even cylindrical illuminance. However, discussions held with working engineers by the authors suggests that such consideration is not always given.

So, what then is good quality lighting? According to the SLL Code[3], good lighting allows you see things quickly and easily without visual discomfort, but also serves to raise the human spirit. Up to now this latter higher ambition has largely been left to dedicated lighting designers implementing imaginative and creative designs.

In Figure 2, the students would have high illuminance on their desks but there is no emphasis on the speaker or on the white board. The screen is self-illuminated, but dimming of main lighting or at least switching off lights at the top of the room is required to create focus and acceptable contrast. The students themselves may be using laptops, tablets and/or phones in which ceiling lights may be reflected, screens thus causing disability glare. Working and living environments are changing and building user demands for higher levels of comfort are increasing.

So, modern work practice is different from previous practice and, in addition to considerations around self-illuminated screens, human interaction is more prevalent. Figures 3a and 3b show modern office

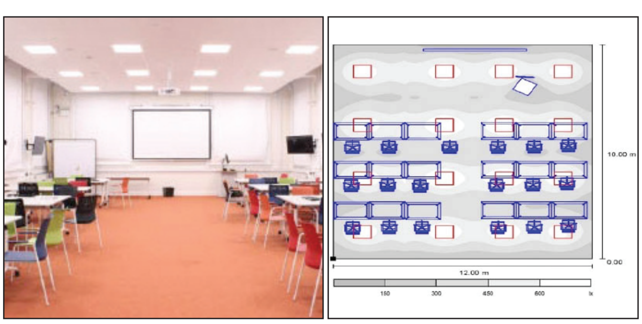


Figure 2a and 2b - Typical classroom using existing methods.

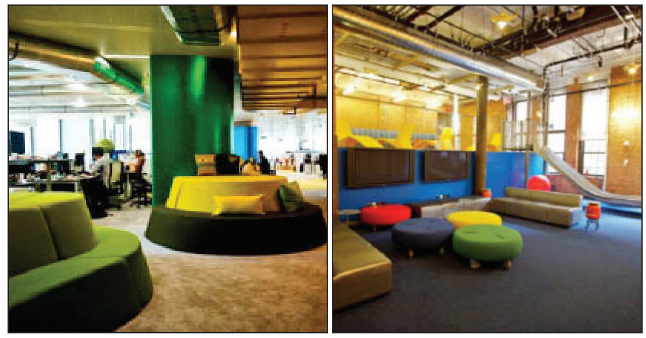


Figure 3a and 3b – Modern office environments.

environments. Staff are focused on self-illuminated screens in a well-lit room where human engagement and interaction require cross vectors of light to provide good modelling and to enable people see each other's reactions as they interact with one another. Reading is typically from self-illuminated tablets, phones or laptops. Even if reading from paper is required, it will not require 500 lux because it will not be for prolonged periods and will probably be from good-quality laser-printed material, (see section 2.4 and Figure 5.)

Because of the changing environment and changing needs of users, Cuttle argues that a new design methodology is now appropriate[7]. This new method can be achieved by consultant engineers using reasonably standard techniques and software for all but the most demanding and high-end projects. In other words, the aim is to raise the standard of office and classroom lighting to good quality lighting, rather than the indifferent quality lighting now accepted as the norm.

A new methodology, invented by Cuttle[8], can make this very achievable. It is proposed we move from designing lighting purely for visual needs to providing lighting that contributes more positively to people's comfort and appreciation of the spaces they work in and inhabit. This means working towards designing lighting for appearance and spatial or surrounding brightness, and then focusing on visual needs, rather than designing lighting for functionality and vision only.

The remainder of this paper will explain what is proposed, examine the implications for existing practice, evaluate the benefits of the new design methodology, and identify the challenges remaining before it can be fully adopted.

2. Literature Review

2.1 Visual Perception and Appearance

Cuttle[8] has suggested that the profession should design interior lighting for appearance using new criteria that would relate to the visual experience of the room occupants. The premise of Cuttle's idea is:

> *"The key to lighting design is the skill to visualise the distribution of light within the volume of a space in terms of how it affects people's perceptions of the space and the objects (including the people) within it. The aim is not to produce lighting that will be noticed, but rather, to provide an envisioned balance of brightness that sets the appearance of individual objects into*

an overall design concept. This is different from current notions of 'good lighting practice', which aim to provide for visibility, whereby 'visual tasks' may be performed efficiently and without promoting fatigue or discomfort". Cuttle[8]

So, lighting design should not just be about providing lighting to make things visible; rather, it should emphasise the overall perception of the lit space. This is radical as he effectively urges the profession to move from *indifferent* design relying only on existing codes and guides, to good *quality* design that lifts the spirit of people using the space. Of course consultant engineering offices must adhere to good practice and follow established codes and guidelines, so any change must involve the legislators and the authors and editors of codes and guides.

In essence,Cuttle[9] suggests two metrics to support this new methodology:

1. Mean Room Surface Exitance – the hypothesis being that MRSE can provide a more reliable metric to measure perceived adequacy of illumination than horizontal work plane illuminance;
2. Target Ambient illuminance Ratio can allow the designer achieve an Illumination Hierarchy in a room that can help improve quality. TAIR is basically considered as a ratio of illumination at a point of emphasis to the general illumination. This is effectively devising illumination hierarchies to highlight visual significance of the space and its contents.

The co-author of the SLL Code, Professor Peter Boyce[10], argued that evidence would be needed to show that MRSE and TAIR lead to more satisfactory lighting and that, if research can provide positive conclusions, then this should become more widely used. Indeed, he suggests it may be one of the few ways with the potential to offer a quantum leap in light quality.

"At the moment, the worth of mean room surface exitance and target/ambient illumination ratio as metrics for determining desirable light distributions are matters of belief rather than proof. What is required is some experimental evidence that mean room surface exitance is related to peoples' perception of the amount of light in a space and that that, in turn, is more closely linked to their satisfaction with the lighting than illuminance on the horizontal working plane". Boyce & Smet[10]

Cuttle[1] argued that MRSE specified-standards would permit a wider range of solutions, particularly as uniformity would not be a criterion. He also suggested that this would allow the integration of lighting and architectural design. He maintained that the engineering-based notion perpetrated by current standards is that illumination uniformity, measured on the horizontal working plane, is a fundamental metric of lighting quality but that this was anathema to lighting designers. He argued for the integration of engineering and design by the lighting profession so that both groups could strive for lighting that is perceived by users to be of good quality.

2.2 Integration of Lighting and Architecture

Integration of lighting and architecture was first addressed by Richard Kelly in the early 1950s in the United States. Kelly[11] referred to three elements of light that have as much application today as they did

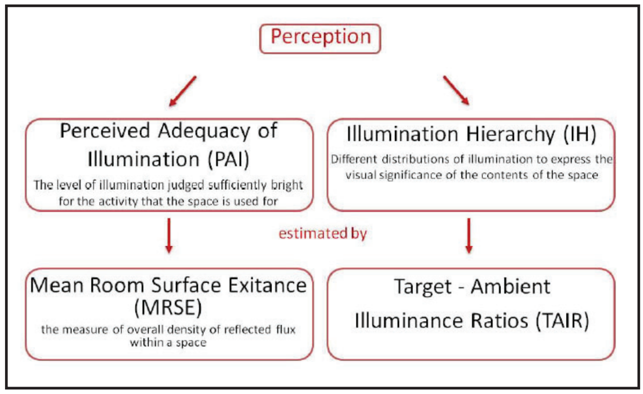


Figure 4 – Two new metrics.

then, and are incorporated into the method that Cuttle is advocating:

1. Ambient Light (shadow-less general illumination) which is often now referred to as spatial brightness, (Cuttle refers to this as surrounding brightness);
2. Focal Glow or Highlight (separating the important from the unimportant);
3. Sharp Detail or Play of Brilliants: this excites the optic nerve and stimulates the spirit.

Cuttle[9] is effectively suggesting that lighting should be designed to bring out flow and sharpness as a part of standard procedure adopted by engineering consultant practices that begins with surrounding brightness, so as to contribute to better quality lighting in all installations … in other words, to enable such lighting to raise the spirit.

2.3 Perceived Adequacy of Illumination(PAI), Mean Room Surface Exitance (MRSE) and Illumination Hierarchy(IH), Target Ambient Illumination Ratio(TAIR)

PAI/MRSE is concerned with providing adequate quantities of reflected flux, i.e., adequate ambient light. The IH criterion focuses on how lighting flows and is distributed to create a pattern of illumination brightness, i.e. to provide the focal glow and detail. This is intended to direct attention to functional activities or create artistic effects. The designer will select target surfaces and designate values of TAIR based on the desired level of illumination difference required.

For example, in Figure 2 the speaker and screen should be at a higher illumination than the rest of the room. Their target illuminations might be a ratio of say 3:1, giving them a distinct appearance compared to the mean brightness level in the room.

Cuttle[1] argues that we need to deal with peoples' perceptions of the space, set luminous hierarchies related to the visual significance of the different scenes, and we need to do this efficiently from a design perspective. Seeing is objective, and illuminance and luminance can both be measured with instruments. Perception on the other hand is subjective and this poses a big problem. How do you measure perception? How is PAI to be measured?

To do this Cuttle[1] invented a new metric called Mean Room Surface Exitance (MRSE) that could be measured and used as part of these new design procedures. MRSE depends on room reflectances and reflectances of furniture and decoration, and this measure integrates the engineering of lighting with the architecture and interior design. This metric was tested as part of PhD research in DIT completed by Duff in late 2015[12].

The second metric TAIR used to establish Illumination Hierarchy is being tested as part of current PhD research in DIT. Figure 4 shows MRSE as the proposed metric for PAI and TAIR as the proposed metric for Illumination Hierarchy. So, we now have two new concepts measured by two new metrics.

2.4 Energy and Iiluminance levels

With regard to pressure on energy use, Cuttle[1] has also challenged the illuminance values specified in codes and standards. In Figure 5, Cuttle showed that a reading task of 12-point type on white paper required just 20 lux to provide for a high level of visual performance. For reading, with font size 6, illuminance would need to exceed 100 lux he concluded. However, even this value of 100 lux falls far short of the illuminance levels currently specified by EN12461-1 and the SLL Code[1] for Lighting, and those specified by CIE and IESNA for applications where reading tasks are prevalent. Cuttle[6] concluded that the levels of illuminance specified by standards, which typically fall within the range 300 to 500 lux, are higher than are necessary for visual performance but yet may still be insufficient for PAI.

This is something that legislators need to be made aware of in relation to the creation of near zero energy buildings, or at least significantly reducing energy in them and hence CO_2 emissions. It will be shown later in this paper that increasing horizontal illuminance does not necessarily contribute to an increased sense of adequacy by building users. It is also apparent from Figure 5 that existing specified levels of illuminance may be too high and it is not clear they are based on any scientific evidence.

There is the likelihood, however, that buildings illuminated to minimum levels of illumination indicated by the above, would be rather gloomy. However, the kernel of Cuttle's ideas are to focus on surrounding brightness levels of buildings and then deal with illuminance on working planes afterwards. Providing sufficient surrounding brightness by dumping more lumens onto a working

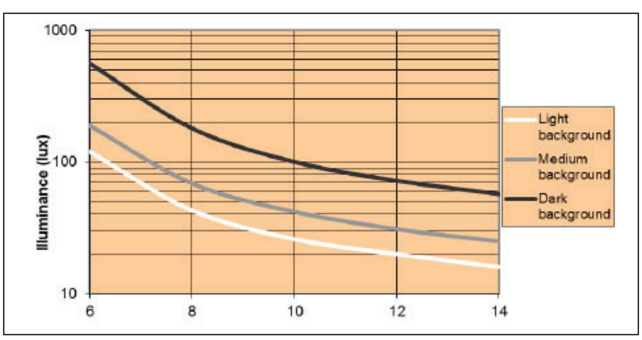


Figure 5 – As applied by Cuttle, the task illuminance required to provide for relative visual performance for a range of reading tasks[9]. The reader is a normal-sighted 25-year-old with a viewing distance of 350mm. The reading matter is black print, ranging from 6 to 14 point size, on three types of paper: light (reflectance (ρ = 0.9); medium (ρ = 0.6); and dark (ρ = 0.3). *Reproduced from Cuttle[1]*

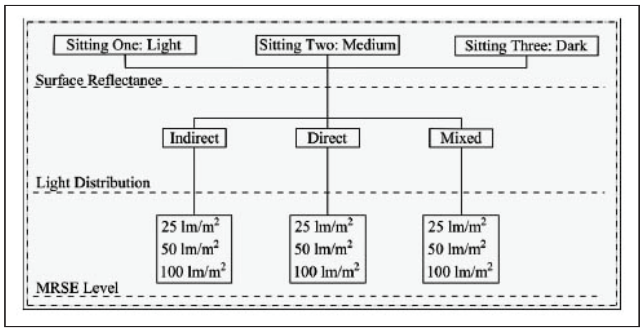


Figure 6 – 27 Light scenes presented to 26 participant.

plane is inherently wrong and energy inefficient, according to Cuttle[9]. Indeed, if the engineer selected luminaires that focused light onto the working plane with the intention of improving efficiency then this is likely to have a negative impact on surrounding brightness. This same engineer may even reject indirect lighting systems with the not illogical view (based on existing standards and practice) that they are inherently inefficient. Research undertaken in DIT suggests otherwise[12],[17].

3. Duff Research

3.1 Initial Research Questions (RQs) with first PhD study by Duff[13]

1. What is the relationship between PAI and spatial (surrounding) brightness?
2. What is the relationship between horizontal illuminance and PAI?
3. What is the relationship between MRSE and PAI?
4. Can MRSE be calculated through lighting design software?
5. Can MRSE be easily measured in the field?

3.2 Summary of research findings

A small test office space in DIT was used under controlled conditions by Duff[12] who examined 27 light scenes as indicated in Figure 8, and surveyed 26 volunteers aged between 18 and 25, with none requiring corrective eyewear. The study examined subjective response to spatial brightness and PAI.

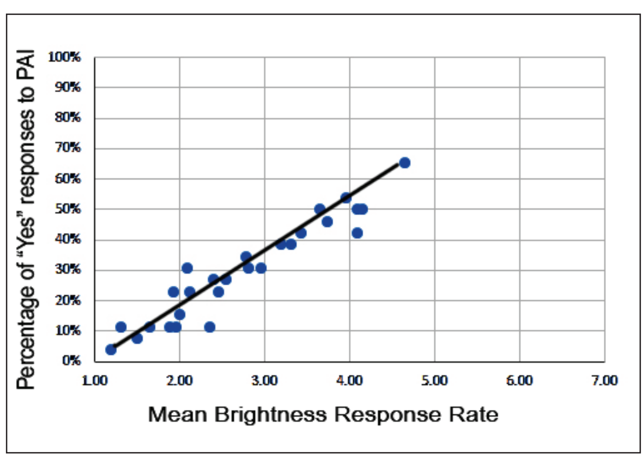


Figure 7 – Spatial (surrounding) brightness and PAI.

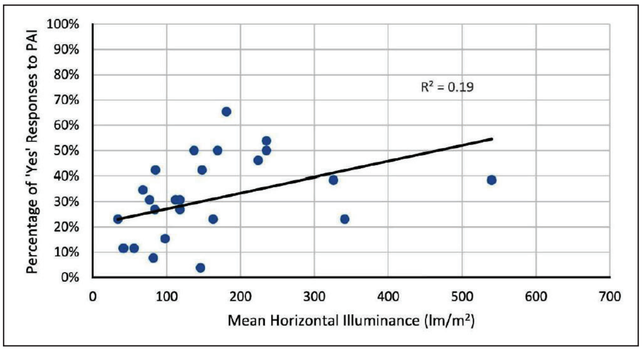


Figure 8 – Yes responses to PAI against Horizontal Illuminance.

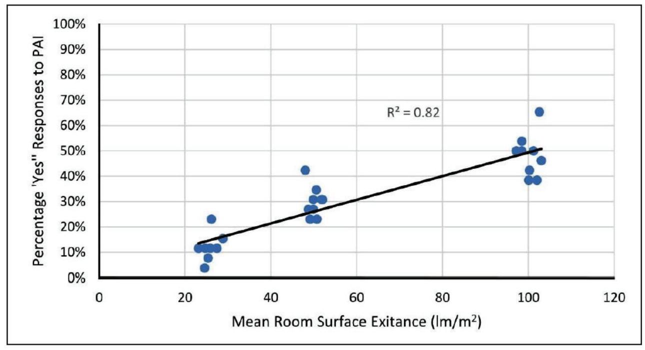


Figure 9 – Yes responses for varying levels of MRSE against PAI.

The study used a real-world office space[13] (approx. 5m x 3m x 3m). Subjects viewed a range of light scenes. Each scene varied the reflectance of surfaces, the light distribution and the quantity of MRSE. When subjects viewed each scene, they were questioned about brightness and whether they believed the lighting was adequate or inadequate.

***RQ1** – What is the relationship between spatial brightness and PAI?*

It was proven in this experiment under controlled conditions that a linear relationship existed between levels of spatial brightness and (PAI) Perceived Adequacy of Illumination, regardless of changes in room surface reflectance or shifts in light distribution. The scatterplot in Figure 7 summarises the data with mean spatial (surrounding) brightness rating of volunteers on the X axis.

Note: The range of conditions in Figure 9 is only for relatively dim to moderate lighting conditions (MRSE levels 25 – 103 lm/m^2).

***RQ2** – What is the relationship between horizontal illuminance and PAI?*

As a separate part of the same study, Duff[14] plotted the percentage of Yes responses to PAI to the traditional method of using horizontal illuminance as the main design metric and perceived adequacy of illumination. Figure 8 shows the outcome. Three outlying points strongly influenced the linear regression model, and excluding these points improves the coefficient of determination to R^2 = 0.56. However, the results in Figure 8 clearly show that horizontal illuminance is not a reliable way of influencing perceived adequacy or, put another way, increasing horizontal illuminance cannot be relied on to increase perceived adequacy. Specifying high levels of horizontal illuminance may be considered wasteful of energy for this reason.

***RQ3** – What is the relationship between MRSE and PAI?*

The relationship between mean room surface exitance and perceived adequacy of illumination was investigated through studies that examined the relationship between MRSE and PAI. It was proven in this study that a simplistic linear relationship existed between level of MRSE and PAI as shown in Figure 9[12]. The studies contained scenes with broadly uniform light distributions

Regardless of light distribution or surface reflectance in this experiment, the level of MRSE had a significant influence on subjects. This study maximised at 100 lm/m^2.

When data in Figure 8 is compared with that in Figure 9, it is clear that the proposed new metric MRSE correlates better to perceived adequacy of illumination than the traditionally-used metric horizontal illuminance (E_h).

***RQ4** – Can MRSE be calculated through lighting design software?*

Duff *et al*[15] developed and validated a radiance script* that is capable of calculating MRSE through currently-available lighting design software. He and colleagues in Arup introduced a method that utilises radiance software as a platform to calculate MRSE[15]. The authors have made the script available for download from a web link given at the end of their paper[15]. MRSE theoretically requires an infinite number of flux inter-reflections, which is not practical given the computing power available to a typical lighting consultant. The authors recommend four to five ambient bounces to be a good trade-off between accuracy and calculation time, but this may need to change when extreme levels of surface reflectance are encountered.

The accuracy of this technique is currently being tested. However, Duff argues that this script is intended only to demonstrate to software developers that the MRSE concept can be easily implemented, ready for mass future use.

**Note: To run the script, users will require an OS X interface with a full suite of Radiance commands installed, along with the ability to run a range of commands in the Perl language. In general, the script works in two parts. The first applies calculation grids to each surface in the space and calculates a mean exitance value for it, the second processes the results to produce the MRSE. The scripts are available at this link: https://www.dropbox.com/l/lC62txkbVpcW1AQ8HPfydu*

***RQ5** – Can MRSE be measured in the field?*

MRSE can currently be measured by recording luminance values on a grid of points on all major room surfaces. Each luminance value is then converted to exitance and the average of all values within a space is representative of the MRSE. This method is slow to implement and its accuracy is limited, and influenced, by the number of grid points that are used. Almost all spaces contain large variations in brightness located over short distances and using a grid with too few points will skew results to an unknown degree.

Duff *et al*[15] have developed a more practical alternative using High Dynamic Range imaging (HDRi). HDR imaging is a set of techniques used in photography to produce a wider dynamic range of luminosity than is typically possible using standard digital imaging or photography techniques. Essentially, HDR imaging uses multiple


Figure 12A and 12B –Standard HDR capture and modified image with direct flux removed[15].

exposures of the same scene to produce images that better represent the perceived luminous environment. At present, this can be applied to produce luminance-calibrated images of the lit environment as developed previously by Mardaljevic et al[16]. This procedure has been adapted by the authors to calculate the indirect flux incident on the camera lens. The intention is that multiple views of a space from various angles are captured, with the mean of the values of indirect luminous flux being equivalent to the MRSE[15].

The accuracy of this technique is also currently being tested but Duff *et al*[15] again emphasise that this procedure is intended only to serve as proof of concept.

6. Ongoing Research

- Further validation is required, and is proceeding, into various aspects of the work to date. Standardisation of measurement procedures for complex areas is ongoing;
- MRSE levels measurement in actual offices and educational spaces is ongoing;
- The tipping point for perceived adequate MRSE level in an office installation will be evaluated to establish a full MRSE scale from very dim to very bright for different applications;
- Ongoing and new research into Illumination Hierarchy (IH) and Target Ambient Illuminance Ratio (TAIR).

7. Discussion and conclusion

Research** undertaken in the Dublin Institute of Technology (DIT)[12] and illustrated in Figure 8 and Figure 9 shows that MRSE is a better indicator of illumination adequacy than horizontal illuminance. The changing level of MRSE within a certain range (25 to 100 lm/m^2) had a significant influence on subjects' perception of lighting adequacy, whereas horizontal illuminance proved not to be a reliable way of influencing perceived adequacy of lighting in the tests undertaken. In defence of horizontal illuminance, there are other metrics which can be used in combination with it to improve quality. Indeed, it has survived for the best part of a century because it was an easy-to-use and reliable system. But times have changed, user needs are different and LED technology offers new opportunities for a more flexible approach.

Apart from the changing nature of work with self-illuminated screens and more human interaction, there is also demand for lower energy use and better quality installations. Intuitively we knew that dumping more lumens onto a working plane in order to increase perceived adequacy was wrong, even before it was proven by Duff that MRSE is a superior metric in this respect. So, Duff's finding are not unexpected for lighting designers. Many of them were already designing lighting schemes in the way suggested by Cuttle. However, what he has proposed are easy-to-apply metrics that can be adopted by all.

In order to implement new practice, consultant engineering practices will need to be assured that design software can be made available and that such lighting schemes can easily be evaluated reliably. Duff[12,15] has also shown proof of concept in this regard, i.e. that software can be developed using the script he has made available and that MRSE can be evaluated or measured using HDR imaging. These findings to date have addressed the substantive challenges set by the industry before MRSE could be seriously considered for adoption in the codes and standards.

It has not yet been proven that (TAIR) is similarly so. This research is ongoing and IH and TAIR will be further investigated, along with ongoing validation and investigation of MRSE. The energy implications of using MRSE/TAIR have still to be addressed but these authors would argue that adopting MRSE/TAIR is justified on quality grounds alone. MRSE/TAIR will now offer a wider range of solutions as uniformity will no longer be a criterion with this new design methodology.

The adoption of MRSE and TAIR as new metrics in interior lighting design can only be successful if there is willingness by the industry to collaborate and engage in this experimental work by adopting this new design practice in selected applications, in other words, lighting designers and consultants willing to implement MRSE/TAIR in real world projects. Changing technology and changing user needs requires a new design methodology. It is a paradigm shift … a whole new way of doing things. MRSE/TAIR is offered as an alternative design methodology to the existing system and should not, in these authors' views, be used as a bolt-on addition to existing practice

In DIT the MRSE/TAIR concept is being implemented in selected areas of existing buildings as retrofit and in selected areas of the new campus buildings presently under construction. Evaluation of these installations will form part of future research.

***Note: More detailed evidence of these findings is also available through Lighting Research & Technology – this is free to download to CIBSE members. Use referenced papers or simply put Duff into search on front page of LR&T website: https://www.cibse.org/society-of-light-and-lighting-sll/lighting-publications/lighting,-research-and-technology-(lr-t).*

Acknowledgements

The lighting research group in DIT comprises the authors, Dr James Duff and Dr Kit Cuttle. This paper draws from their work and could not have been written without them.

References

[1] Cuttle C. *A New Direction for General Lighting Practice* (inc. discussion). Lighting Research & Technology, 2013; 45(1): 22-39. (Awarded the Leon Gaster Award, 2013) doi: 10.1177/1477153512469201

[2] Tulla A. Editorial Newsletter. The Society of Light and Lighting Jan/Feb, 2008; 1(1).

[3] SLL (2012) *Code for Lighting*, published by the Society of Light & Lighting which is part of the Chartered Institution of Building Services Engineers, London.

[4] European Committee for Standardization, Light and lighting – lighting of work places – Part 1: indoor work places CSN EN 12464-1, 2011, Brussels; CEN.

[5] Society of Light and Lighting (2009) *The SLL Lighting Handbook, London*; CIBSE.

[6] SLL Lighting Guides 1 to 14 published by Chartered Institution of Building Services Engineers, London.

[7] Cuttle C. (2015) Overcoming a Divided Profession. Lighting Research & Technology, 2015 Opinion Piece 47(3): 258.

[8] Cuttle C. (2010) Towards the Third Stage of the Lighting Profession. Lighting Research & Technology, 42(1): 73-93..

[9] Cuttle C. (2015) Lighting Design, a Perception Based Approach; Routledge UK & NY.

[10] Boyce P.R. & Smet K.A.G. (2014) *LRT Symposium, Better metrics for better lighting – a summary*. Lighting Research & Technology 2014 Vol. 46: 619-636.

[11] Kelly, R (1952) *Lighting as an Integral part of Architecture*. College Art Journal, 12(1): 24-30. doi: 10.2307/773361

[12] Duff, J. (2015) On a new Method for Interior Lighting Design, PhD dissertation, Dublin Institute of Technology.

[13] Duff J, Kelly K, Cuttle C. (2017) Perceived adequacy of illumination, spatial brightness, horizontal illuminance and mean room surface exitance in a small office. Lighting Research and Technology; 49(2): 133-146. doi:1477153515599189.

[14] Duff J, Kelly K, Cuttle C. (2017) Spatial brightness, horizontal illuminance and mean room surface exitance in a lighting booth. Lighting Research and Technology; 49(1): 5-15. doi: 1477153515597733

[15] Duff J, Antonutto M and Torres S (2016) On the calculation and measurement of mean room surface exitance; Lighting Research & Technology. 2016; Vol. 48: 384–388.

[16] Mardaljevic, J. Painter, B. Andersen, M. (2019) Transmission illuminance proxy HDR imaging: A new technique to quantify luminous flux. Lighting Research and Technology; 41:27–49..

[17] Cuttle, C. (2017) Development and Evaluation of a New Interior Lighting Design Methodology. PhD dissertation, Dublin Institute of Technology.