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A new approach to interior lighting design :early stage research in Ireland

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Abstract

Current standards for interior lighting design are discussed and an alternative design methodology proposed. Cuttle has previously suggested a new criterion be defined as perceived adequacy of illumination (PAI), and that the metric for specifying minimum illumination standards becomes mean room surface exitance (MRSE). This metric specifies the overall brightness of illumination, enabling its distribution to be planned in terms of target/ ambient illuminance ratio (TAIR). This new methodology is explained, analysed and discussed along with on-going research at the Dublin Institute of Technology.

Introduction

Lighting designers exercise their creativity against a backdrop of codes[1,2,3], standards[4], and recommended practice documents[5], each specifying a range of lighting parameters for compliance. Foremost among this is a schedule of minimum illuminance values related to various indoor activities. While it is accepted that standards are necessary for general lighting practice, it has been quite common in the past for experienced lighting designers to sometimes disregard these standards as being irrelevant to their work. That attitude has become untenable due to the growth of regulations[6] governing energy efficiency and sustainability. The practice of specifying indoor illumination in terms of workplane illuminance has been firmly established by the Commission internationale de l'éclairage (CIE) and the engineering-based lighting societies, and the energy regulators have followed this practice pretty strictly.

This paper will discuss current standards and their relevance, introduce a new methodology for designing lighting within interiors, and briefly describe some ongoing research that is examining the suitability of the newly-proposed method.

Illumination schedules

Although specifying bodies have added various *lighting quality* criteria to their pronouncements[7,8], the central factor remains the workplane illuminance, and it is claimed that this quantity is determined primarily by the category of the visual task. *The IESNA Lighting Handbook*[1] states that *"Changes in visual performance as a function of task contrast and size, background reflectance, and observer age can be calculated precisely".* Cuttle has previously[9] applied the referenced procedure[10] to examine how the illuminance required for a high standard of visual performance relates to various reading tasks.

Figure 1 shows that, for the typical reading task of 12-pt type on white paper, it requires just 20 lux to provide for the relative visual performance criterion of RVP=0.98, this value being generally accepted as the highest practical RVP level for lighting applications. It can be seen that the font size would have to be reduced to 6-pt for the required illuminance to exceed 100 lux, or alternatively, reduced to 10-pt but printed onto dark-coloured paper, which has the double effect of reducing the background luminance and the task contrast.

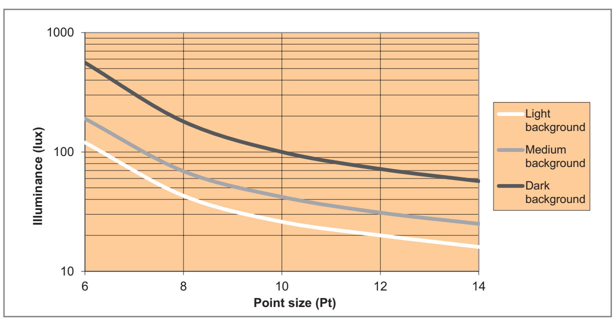

Figure 1: As previously applied by Cuttle, the illuminance necessary for high levels of RVP under varying illuminance levels, text size and background contrast.

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However, this value of 100 lux falls far short of the levels conventionally provided for applications where reading tasks are prevalent, and which typically fall within the range 300 to 500 lux. It is argued that such levels can be justified on the basis of visual performance only by presuming that either the users are partially visually defective, or that they are persistently required to read very small print with very low contrast on low reflectance backgrounds.

If this is not enough, we should not lose sight of the fact that indoor spaces in which reading tasks (or tasks of similar visual difficulty) are prevalent are not the universal norm. There are far more spaces that we pass through, or in which we engage in social or recreational activities, where our visual needs are much more simple, and often comprise nothing more than the ability to be able to navigate through a furnished space freely and safely. How much light do we need to do this? In a study[11] of emergency egress from buildings, Boyce conditioned subjects to 500 lux in an open-plan office before plunging them into low, or very low, illuminance levels, with the instruction that they were to find their way out. As well as timing them, he had installed infra-red cameras so he could monitor their progress, and he concluded: *"At a mean illuminance of 1.0 lux on the escape route people are able to move smoothly and steadily through the space at a speed very little different from that achieved under normal room lighting."*

From the previous paragraphs, it is evident that within indoor spaces where reading tasks are prevalent, such as offices, classrooms and libraries, we commonly provide illuminance levels that are between 15 and 25 times as much as people actually need for high levels of visual performance. As for spaces where finding one's way is the foremost demand on our visual faculties, such as shopping malls interiors and airport terminals, we over-provide by several hundred fold. There are colossal differences between the illuminance levels required for the visual performance criteria that standards are claimed to ensure, and the levels that the standards specify.

Lighting for human satisfaction, or something else?

The *Illuminating Engineer* published by the IES of Great Britain in October 1911[12] over 100 years ago includes a report titled *Illumination requirements for various purposes*. Contained within is a table listing 34 activities along with corresponding illuminance values based on several field surveys. Regarding the aforementioned tasks, reading (ordinary print) is listed at 30 lux; and schoolrooms are also at 30 lux; commercial offices are 40 lux; and libraries range from general, 15 lux, to bookshelves, 25 lux and reading tables 50 lux. Admittedly, none of the indoor activities go as low as the 1 lux finding from the emergency egress research, but broadly, if allowance is made for the fact that these field-measured values precede not only photocopiers and laser printers but also any visual performance studies, it can be seen that general lighting practice of 100 years ago showed substantial agreement with the data presented in Figure 1.

This begs the questions, why are the levels demanded for current lighting practice so substantially in excess of those levels? No serious proposition could be mounted on the basis of deteriorating human visual abilities, or on increasing difficulty of visual tasks. The answer is rather obvious. If any modern buildings were illuminated to such low levels, people would choose to avoid them. If such lighting was to be imposed upon employees, or some other captive group, there would likely be outrage. Public opinion would be united that nobody should have to tolerate such dismal, gloomy conditions. This is the main point of the matter. It is nothing to do with the speed and accuracy with which people are able to detect the critical detail of visual tasks. Rather, it is about meeting people's expectations that, here in the 21st century, the variety of spaces that we all pass through, occupy and engage in for recreational, social and work activities, should appear to be adequately illuminated. During the past 60 years we have made the transition from providing for visual needs to meeting human expectations.

Perceived adequacy of illumination

Do the elevated illuminance levels of current practice mean that the standards have adapted to changing expectations and that the present situation is quite satisfactory? The current standards specify lighting quantity in terms of visual task illuminance and, as we have seen, this is generally interpreted as the average illuminance of the horizontal workplane. It follows that for lighting to be efficient, economical and purposeful, the lamp lumens must be directed onto the workplane with high optical efficiency.

Furthermore, to direct light onto walls, ceilings or other features that might catch the eye is deemed inefficient and wasteful. The evidence of this rationale is all around us in general lighting practice, and lighting designers can expect to encounter increasing pressure to follow this trend as providing a specified workplane illuminance with minimal lighting power density is widely recognised as pursuing the holy grail of sustainability.

As has been mentioned, there has been a recent tendency among specifying bodies to add lighting-quality criteria to their stipulations, but this is not enough. What is needed is a fundamental re-evaluation of whether or not the users of a space are likely to judge it to appear adequately illuminated, or to put it another way, what is the photometric correlate to the *perceived adequacy of illumination?*[9,13]

Mean room surface exitance

Cuttle has previously introduced the concept of mean room surface exitance (MRSE) as a metric that serves as an indicator of typical assessment of the brightness of illumination of an indoor space[14,15]. To understand the concept of exitance, keep in mind that while illuminance is concerned with the density of luminous flux *incident* on a surface, exitance concerns the flux *exiting*, or emerging from, a surface. MRSE is, within the volume of the room, the average density of lumens emerging from all of the surrounding room surfaces. Within an enclosed space, this is flux available for vision, and so MRSE could be measured at the eye and includes only light that has undergone at least one reflection (i.e. direct light is excluded). It may be thought of as an indicator of the level of the light that brightens the view of indoor surroundings, and which is independent of any effects of bright luminaires or windows.

It has been proposed by Cuttle that MRSE may be applied as an indicator for perceived adequacy of illumination (PAI) which is a binary assessment, that is to say, in a given situation, the illumination may be perceived as either adequate or inadequate, so that PAI would be specified by a single MRSE value. However, it is logical that an MRSE level that might be judged adequate in a waiting room or an elevator lobby might be considered inadequate in a workplace or a fast food outlet.

Designing for appearance

While the PAI criterion is concerned with providing adequate quantities of reflected flux, an illumination hierarchy focuses on how direct flux from luminaires is distributed to create a pattern of illumination brightness. Creating an illumination hierarchy involves devising distributions of illumination to express the visual significance of the contents of the space. Cuttle has previously suggested[13] that it be specified in terms of target/ambient illuminance ratio (TAIR) being the ratio of local illuminance on a target to the ambient illumination, indicated by the MRSE. This may direct attention to functional activities or create artistic

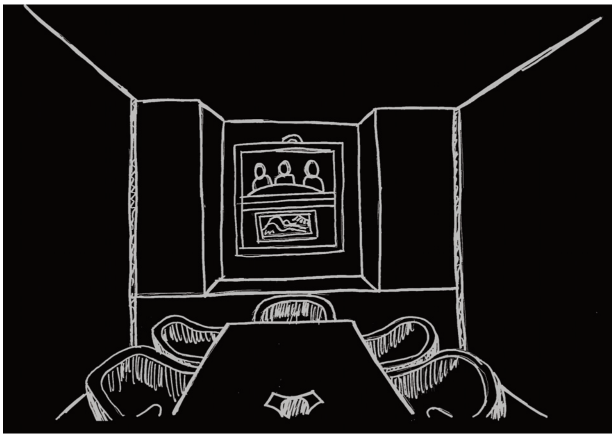

Figure 2a – Meeting room

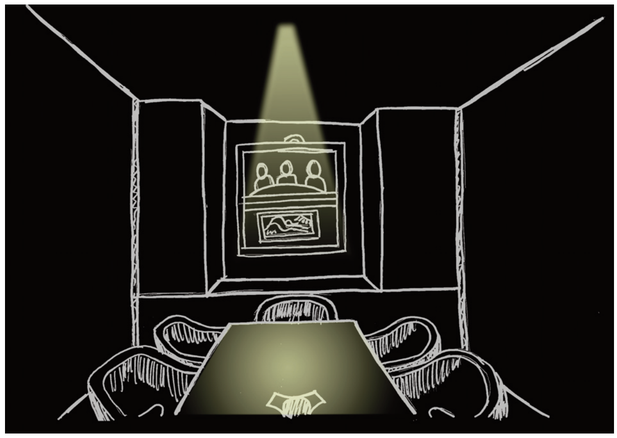

Figure 2b –Downlight provide 300 lux on the table

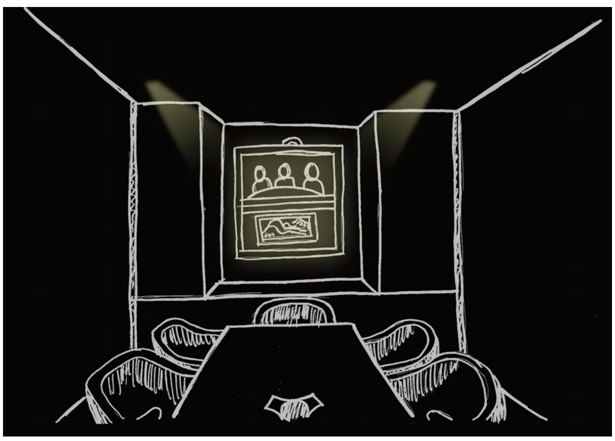

Figure 2c – Spots provide 200 lux on the artwork

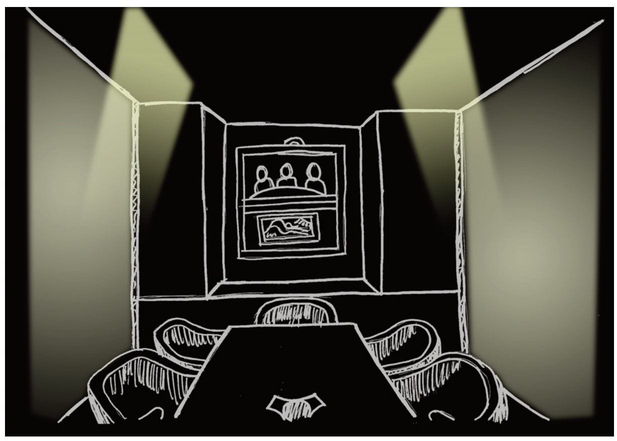

Figure 2d – Wallwash provides 300 lux on the walls

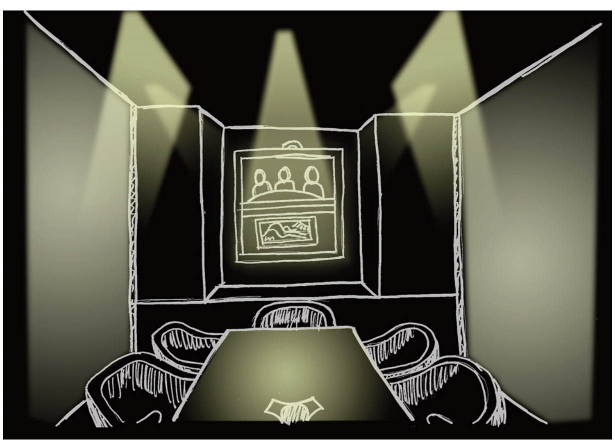

Figure 2e – The derived illumination hierarchy

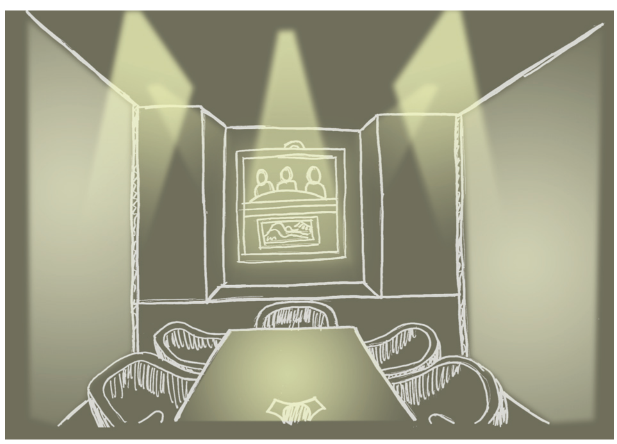

Figure 2f – Reflected flux creates ambient illumination (MRSE)

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effects. The designer will select target surfaces and designate values of TAIR based on the desired level of illumination difference required.

Figures 2a – 2f walk through a typical design process for a meeting room. Initially the designer will select an amount of ambient illumination he/she believes will be appropriate. This will be given by the MRSE, which in the future may be taken from standards or personal experience, but for this example, 100lm/m^2 is used. Following this, objects or surfaces of significance within the space are identified and consideration given to how much brighter, or darker, relative to the ambient illumination the designer would like these to be.

Three objects of significance are the table, the side walls and the artwork on the end wall. All three surfaces should be brighter than the ambient illumination. A simple solution might be to place a single downlight in the ceiling to provide 300 lux on the table (a TAIR value of 3), use ceiling spots to give 200 lux on the artwork (a TAIR value of 2), and wash the walls to 250 lux (a TAIR value of 2.5). Each of these is illustrated in Figures 2b, 2c and 2d respectively. Once this is complete, an illumination hierarchy has been established (Figure 2e). The quantity of light reflected from the highlighted surfaces will then determine the ambient illumination (Figure 2f) and is quantifiable through calculation of MRSE. Once MRSE is calculated for the current arrangement, it can be compared with the design intent of 100lm/m^2 and additional modifications made as required.

Barriers to implementation

Since its introduction, the approach described has received both positive and negative feedback from the lighting community. Some believe that this proposition is doomed to failure due to lack of information available at design stage[16,17]. While this may hold true, Boyce points out that in the face of such ignorance, it is unreasonable to expect that good-quality lighting will be the outcome of any design method[18]. Many agree that current codes and standards are long overdue a transformation[19,20,21] and indeed some currently choose to ignore them[22].

Brandston criticises current codes and building regulations for demanding an excessive quantity of illuminance on the task, leaving little remaining power density to light the space[22]. Others have noted that senior directors within notable building services firms refuse to deviate from standards and codes for the fear that their professional indemnity insurance will be affected[23]. This demonstrates that current lighting standards are placing substantial restrictions on designing for appearance, thus limiting creative design and potentially impeding good-quality lighting. Loe comments[24] that subjects he has studied[25] prefer environments that are visually bright and visually interesting.

While MRSE may never provide this, it is a fair assumption to state that the IH criterion might produce a visually bright and visually interesting space. Macrae believes the procedure to be *"fundamentally flawed"* as to apply the methodology correctly requires a good understanding of light and lighting[17]; but should this not be mandatory for those involved in lighting? If good-quality lighting is the desired outcome, then the answer must be yes.

Critics of Cuttle's earlier paper[16,26,27], based solely on MRSE, voiced concerns that there may be enough light arriving at the observer's eye, but insufficient illuminance upon a task. If applied correctly and with due thought, the IH criterion would designate strenuous visual tasks with a TAIR of above three and this should, combined with a sensible MRSE, quite comfortably provide adequate illuminance levels for optimum visual performance.

Boyce agrees[28] that visual tasks have become easier over time, but questions if what people really care about is the perceived brightness of a space. Boyce points out that MRSE is a crude measure of brightness and the range of luminances in the field of view, combined with source spectrum, will also be important[28]. This raises an important point; producing a simple metric that incorporates all of these variables is a daunting task and would almost certainly go beyond the scope of what lighting standards are expected to do. Raynham states[26] that MRSE cannot become the *"be-all and end-all of lighting design"*, but this statement was made before the introduction of the IH criterion, which adds an additional dimension to MRSE-based design.

Despite the initial criticism, there was a substantial amount of positive support. In a more recent publication[19], Boyce promotes MRSE and TAIR together as a methodology that shows potential to improve the quality of lighting, so it would appear that as Cuttle's design theories have progressed to include illumination hierarchies, Boyce has become convinced that this method shows considerable potential. Boyce states that by adopting MRSE-based designs, *"light distributions that illuminate the walls and ceiling then become much more energy efficient than those that concentrate their output onto the horizontal working plane"*[19]. Loe agrees with designing for ambience[24]. Shaw states that *"this is one of those blindingly-obvious ideas that we have all missed"*[21]. Poulton points out that codes and standards are *"archaic and should be revised"* and that Cuttle's way of thinking is *"long overdue"*[20].

Hogget believes that the proposition is what talented lighting designers have intuitively been doing for years when using a mathematical technique to quantify the task/ambient ratio. Mansfield states that Cuttle's suggestion to use MRSE as an exploratory tool to define illumination adequacy is a good one and welcomes further dissemination of it as a tool for teaching and as a device to re-align lighting design practice[30].

Brandston states that the approach is in line with his own. Brandston initially lights the space and then pays attention to the tasks[22]. Wilde agrees that dumping lumens on a working plane is fraught with problems[23]. Wilde believes that it is time to change from visibility to appearance and goes on to state that *"it must be welcomed by the discerning designer"*[23]. Boyce describes the MRSE/TAIR procedure as *"all-encompassing"*[19] and highlights that the first step towards implementation would be the modification of current software, or development of appropria new software[19]. This sentiment is supported by Wilde[23]. While the importance of this has been recognised, there are other concerns that need to be addressed before this can take place.

The first step should be systematically proving that MRSE relates to occupant assessments of illumination adequacy and in turn, devising a range of MRSE values that will relate to PAI for spaces that house various activities. The second step is measurement. Quantifying MRSE in-field is not an easy task. A grid of luminance values can be recorded on each surface of a space and converted to exitance to estimate the total MRSE, but this method is cumbersome and time-consuming. High Dynamic Range (HDR) imaging has been proposed, but this will need to be modified so pixels within the camera field of view that contain direct luminance can be excluded.

If these two steps can be overcome, it is argued that this new methodology shows much potential to improve the quality of lighting within general installations. It directs attention away from the working plane and places emphasis upon the appearance of a space; it pays due attention to levels of brightness and illumination hierarchies; and, with some slight modifications, it could be readily implemented through software, which is how all lighting design is done today.

Research

At the Dublin Institute of Technology (DIT) ongoing research is attempting to better understand the relationship between MRSE and PAI, in addition to devising an accurate and robust methodology to measure MRSE in-field. The following briefly outlines the methods and expected outcomes of each.

Measurement of MRSE

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.

An alternative method is being developed using High Dynamic Range imaging (HDRi). HDRi 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 photographing techniques. Essentially, HDRi uses multiple 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 (but not exitance) images of the lit environment[31,32].

This procedure has been utilised in conjunction with RADIANCE and MATLAB to produce estimates of MRSE. For any standard HDR image the written script can be applied which removes direct flux and simultaneously spits out a numerical value for the quantity of indirect flux incident on that camera view (Figures 3a and 3b). The average of multiple views of the same scene can then be used to estimate the MRSE. The accuracy of this technique is currently being tested against real world measurement and also triangulated against simulation data produced in RADIANCE. Early results have sometimes produced percentage errors close to 20% compared to real world measurements. The script is currently undergoing modification with various options being tested. The intention is to improve accuracy such that results within a 10% error margin can be guaranteed.

Figure 3a – Standard HDR capture

Figure 3b – Modified image with direct flux removed

The relationship between mean room surface exitance and perceived adequacy of illumination

Two pilot studies have been conducted that examined the relationship between MRSE and PAI. The first of these studies used a scale lighting booth (approx. 2m x 1m x 1m) and the second a larger real-world space (approx. 5m x 3m x 3m). Despite being two separate studies, both used matching methodologies and identical subject groups.

In each experiment 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. Figures 4a – 4f show generic representations of the typical light distributions subjects were exposed to and subjects also viewed these distributions over a number of levels of surface reflectance and MRSE.

These results are presently being analysed to provide a better understanding of the relationship between MRSE and PAI. It is

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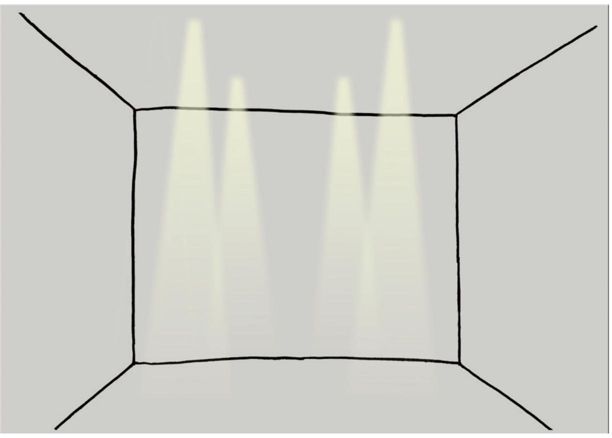

Figure 4a – A uniform downlight distribution

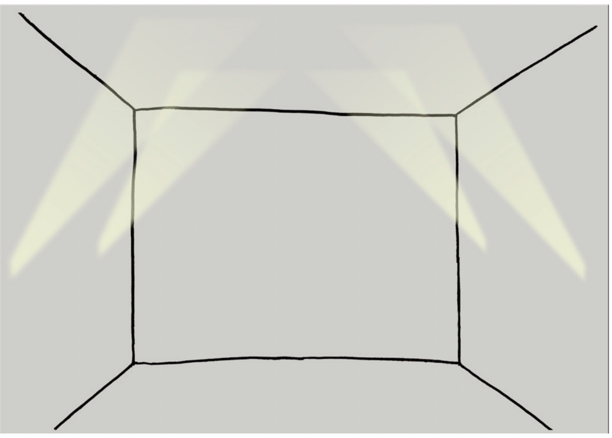

Figure 4b – A uniform uplight distribution

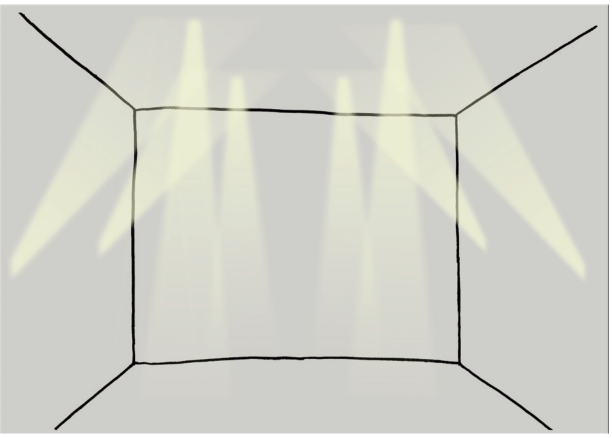

Figure 4c – A uniform mixed distribution

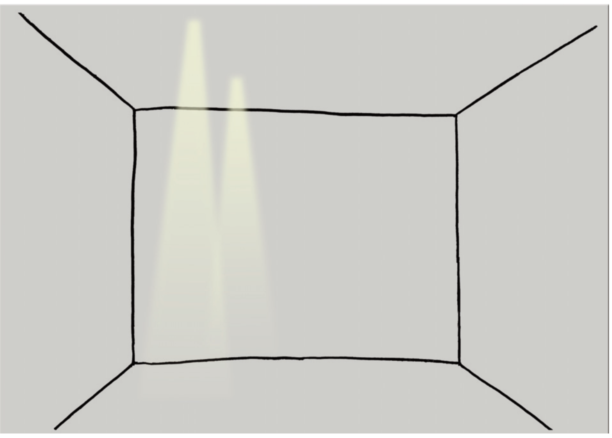

Figure 4d – A non-uniform downlight distribution

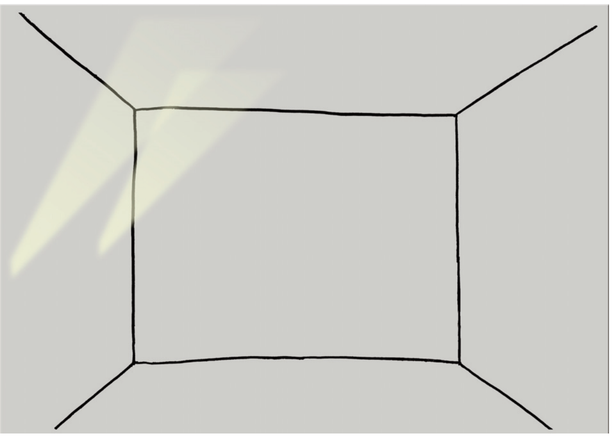

Figure 4e – a non-uniform rosbuimedia@eircom.net

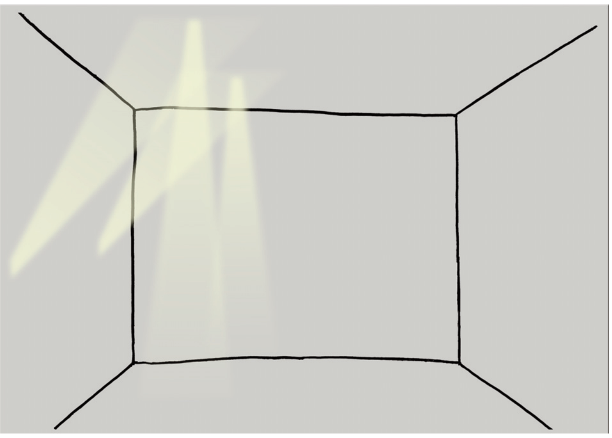

Figure 4f – A non-uniform mixed distribution

expected that indications of which variables influence subjective assessments under certain conditions will emerge. This is critical to advancing this research and allowing this new method of lighting design to progress. Findings from this work will enable further studies to examine the quantity of MRSE that people believe is appropriate for a range of situations and space usages.

Conclusion

A new design methodology for general interior lighting practice has been explained and critically examined. It has received positive and negative feedback from the lighting community, but the majority now appear to be in favour of a move away from where lighting standards are currently at and towards a method that pays greater attention to the appearance of a space. The method discussed here is seen to show promise because it directs attention away from the working plane, it defines levels of brightness and, if adopted, it could be readily implemented through software.

Two barriers to implementing this method in standards are:

– How MRSE is measured in-field;

– Understanding the relationship between MRSE and PAI.

Both of these items are being addressed at the Dublin Institute of Technology and will be reported further in future research papers.

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