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Lighting Design in Europe: Aligning the Demands for Lower Energy Usage with Better Quality

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Abstract: Lighting design is one of the fastest changing areas in building engineering. It has evolved significantly in recent years due to changing technology and demands for improved quality, better control, reduced energy and sustainability. This paper is an overview of what is happening in Europe and elsewhere and examines the literature to find that latest recommendations in the Code for Lighting issued by the SLL (Society of Light and Lighting) in the UK change previous demands for equal illuminance across a working plane to more specific and demanding criteria. There are recommendations for qualitative metrics and better distribution of light so as to enhance the visual appearance of interiors. European standards are also examined and the LENI (lighting energy numerical indicator) has been found to be a better way of reducing energy than installed load. New LED (light-emitting diode) lamp technology is examined and daylight is discussed in the context of these changing demands. It is found that lighting standards and design are changing for the better but that standards will need to evolve further if they are to ensure good quality lighting.

Key words: Lighting, energy use, daylight, LEDs and LENI.

1. Introduction

This paper begins by detailing how changes to the Code for Interior Lighting issued by the SLL (Society of Light and Lighting) [1] are affecting lighting design in the UK, Ireland, and wider afield, where the SLL Code is used. SLL has regional committees in Australia, New Zealand, the Middle East, Hong Kong and actively participates in the formulation of European standards. SLL has members in 94 countries. The SLL Code is entirely consistent with European standards and directives, to which SLL has contributed, and these European standards are also referred to with respect to the LENI (lighting energy numerical indicator). Latest standards and recommendations change previous demands for equal illuminance across an entire space and make recommendations for qualitative metrics and distribution of light, combined with demands for improved control and energy efficiency.

Energy efficiency and user satisfaction can be improved with increased daylight and this is discussed in this context. There are significant developments in lamp technology. LED (light-emitting diode) lamp technology is expected to be an $80 billion industry by the 2020s [2], and this technology is improving at an exponential rate. But LEDs can be expensive to install and are not without problems. This paper provides useful guidance to those intending to specify or use LED lamps based on the authors' own research and publications.

2. Current Guidance, Recent Changes and the Limitations of Guidance Documents

The SLL [3], previously named the Illuminating Engineers Society and founded in 1911, has provided guidance for the lighting industry in the UK and further afield since 1936. SLL now writes a wide variety of design guides for the lighting sector. The SLL Code for Lighting [1] and accompanying lighting

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handbook [3] provide a summary of lighting standards and offer further qualitative guidance, which combines to provide a comprehensive text on lighting. In recent years, the CEN (European Committee for Standardization) has also set standards for all countries in Europe. Although there are many standards, the most important are EN 12464 Lighting for Workplaces and EN 15193 the Energy Performance of Buildings Directive. In EN 12464, minimum requirements for lighting are laid down for both interior (Part 1) [4] and exterior (Part 2) [5] lighting. EN 12464 specifies many quantitative criteria, but the most prominent are:

- maintained illuminance;
- uniformity;
- color rendering index;
- unified glare rating.

Maintained illuminance is the quantity of light that a lighting installation will provide at the end of a maintenance cycle, uniformity is the ratio of the average illuminance compared to the minimum illuminance, and color rendering index is a measure of the appearance of colors under certain light sources and unified glare rating is an estimation of visual comfort. In recent years, standards have changed. The full implications of this are explained elsewhere [6, 7], but the main changes are summarized in Table 1.

It is no longer recommended to illuminate an entire space at working plane height to a given illuminance level [1, 4]. It is now suggested that lighting designers work with their design team to finalize the task area within a space and illuminate this to a suitable illuminance, with the remainder of the space illuminated to a lower illuminance [1, 4]. The aims of this are to provide visual interest, which has been shown to increase occupant concentration and satisfaction within spaces [8], and reduce energy consumption.

Specifying a minimum quantity of light on the major surfaces of a space will help ensure that there is enough light with an occupants' field of view such that a space will be perceived as bright [5].

The introduction of cylindrical illuminance and modeling index are stated as being "a big step forward in recognizing the importance of the visibility of peoples' faces and objects, within a space" (Figs. 1 and 2) [1].

Minimum levels of cylindrical illuminance and an appropriate modeling index will highlight objects, reveal textures, aid facial recognition and allow for better integration of electric lighting and daylight [1, 9].

Increased room surface reflectances will allow for an increased quantity of reflected light, which will increase the brightness of a space, in some cases quite significantly. Duff and Kelly [7] have shown that increasing the average reflectance of the surfaces within a small test room from 29% to 52% produced more than a 200% increase in the perceived brightness of the space, under constant quantities of illuminance.

EN 15193 [10] recommends a specific method for the calculation of lighting energy consumption that goes beyond simple W/m^2. The LENI allows the calculation of energy to be used by an installation, taking into account the benefit of automatic lighting controls (see Section 6).

Table 1 A summary of the main changes to the SLL Code for Lighting [6, 7, 10].

Older codes	2012 Code
Illuminating entire horizontal plane	Focusing light where it is needed
Illuminance on working plane only	Minimum levels of illuminance on major room surfaces to enhance appearance
Increased lighting when reflectances low	Demands for increased room surface reflectances
Reference to vector/scalar ratio	Metrics which account for illuminating objects and peoples' faces
Specified maximum power/space and ignoring usage	Method for calculating energy consumption (LENI) that accounts for daylight and control

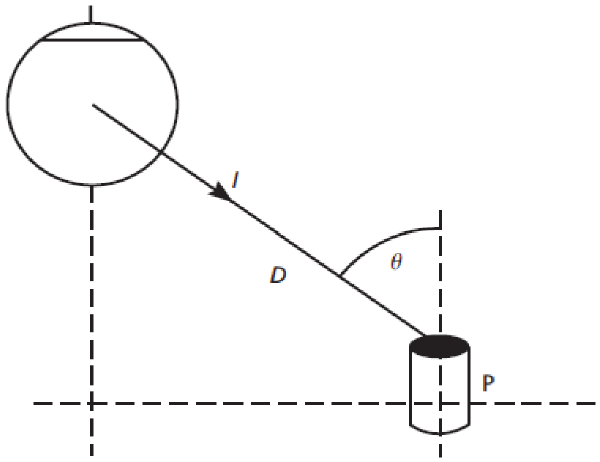

Fig. 1 A graphical illustration of cylindrical illuminance, being the quantity of light falling on the curved surface of an indefinitely small cylinder [1].

3. Limitations of Standards

In a search for what exactly the purpose of lighting guidance is, Boyce [11] attempts to define lighting quality: "bad quality lighting is lighting which does not allow you to see what you need to see quickly and easily and/or causes visual discomfort. Indifferent quality lighting is lighting which does allow you to see what you need to see quickly and easily and does not cause visual discomfort but does nothing to lift the spirit. Good-quality lighting is lighting that allows you to see what you need to see quickly and easily and does not cause visual discomfort but does raise the human spirit".

Boyce [12] later proceeds to show that lighting guidance will only eliminate bad lighting and is likely to ensure only indifferent lighting [12]. He suggests that at present, to produce good quality lighting, a team of a talented architect and a creative lighting designer are necessary. This shows the limitations of lighting guidance and standards. Simply following them will not produce good quality lighting. Boyce [12] explores methods which may bridge the gap between indifferent and good quality lighting such as proposals by Cuttle [13-19] and proposes that if none of these are accepted and adopted in the future, then good quality lighting will only be available to those who can afford the services of a creative, experienced and talented lighting designer.

4. Daylight

People love daylight and spaces that make extensive use of it are generally considered attractive, but they do not love it unconditionally [20, 21]. Like many other light sources, daylight has to be controlled to avoid visual discomfort as well as thermal discomfort. Mardaljevic [22] argues that we must advance beyond using daylight factors towards a more realistic quantification of daylighting performance and evaluation. He suggests ways of doing this with relatively modest additional effort. The key point here

(a) (b) (c)

Fig. 2 Modeling of a bust by different light distributions: (a) completely diffuse lighting; (b) strong down-lighting; (c) a combination of directional and diffuse lighting [1].

Source: reproduced by kind permission of SLL.

is that daylighting through windows can create a bright and interesting visual environment with strong cross vectors of light which facilitates good modeling. Brightness and interest are of importance as these are two of the dimensions by which people assess the quality of a working space [8]. Variation of daylight throughout the day delivers meaningful information about the passage of time and the view out can provide useful stimulation. Buildings where daylight is thoughtfully distributed without visual or thermal discomfort are considered better buildings [20]. Maximizing daylight and minimizing energy used by electric lighting must take place in a way that minimizes overall energy consumption from the building. It is unacceptable to maximize daylight to reduce light energy if thermal energy requirements increase due to the need for extra heating or cooling. It should be remembered that extra glazing for increased daylight would increase heating load in winter and cooling load in summer, whilst the alternative of increased electric lighting usage can also significantly contribute to building cooling load requirements. So this is a complicated balance, which varies with building type, construction, orientation, usage and location.

5. Light Emitting Diodes

For people reading commercial lighting publications or attending lighting trade shows, it would seem that there is a single solution for all lighting problems—LEDs. OLEDs (organic LEDs) are a half decade or more further behind LEDs but have very exciting potential too—albeit presently at prohibitive cost.

Boyce's [23] editorial in lighting research and technology in June 2013 concludes that the growth of LEDs has happened for three reasons: the first is the immense quantity of money invested in LED technology by lighting manufacturers and the consequent rapid development in their capabilities; the second has been the enthusiasm of regulators who see LEDs as the ultimate replacement for incandescent; and the third is fashion. At present, opting for LEDs is considered progressive, enlightened and fashionable. The outcome of these factors has been explosive growth in the LED market, and similar to all such markets, it has attracted many new suppliers. Some of these have a reputation to uphold and do so, but many do not. As a result, the market is now saturated with LED products of unknown pedigree. This raises an issue for designers, specifiers and purchasers: how can they distinguish good equipment from bad? Surely lighting research can provide this answer? Sadly, up to now, independent research has not been able to keep up with the rapid developments in this technology sufficiently. As a result, very little guidance is available for the purchaser when selecting LED equipment [18]. Boyce [12] challenged the lighting community to address this and suggested that a valuable contribution would be a set of standard, simple questions to ask the LED supplier. Duff [23-26] has provided Boyce with a set of these questions and appropriate answers in the LR&T (Lighting Research and Technology) and SDAR (Journal of Sustainable Engineering Design).

It is suggested that any supplier who is unwilling, or unable, to answer these questions should be treated with caution. The questions proposed help address some of the major issues associated with LED products. Until recently, not many standards were in place to regulate the construction, manufacture, performance and operation of LEDs, but in recent years, this has improved somewhat with the introduction of "LM-79-08, IES Approved Method for the Electrical and Photometric Measurement of Solid-State Lighting Products" [27] and "LM-80-08, IES Approved Method: Measuring Lumen Maintenance of Light Emitting Diode Light Sources" [28]. Both of these test methods allow manufacturers to have their products tested in an independent laboratory, to a standard set of testing procedures. This offers designers, purchasers and specifiers a fair comparison between products. Now that this standard set of test procedures is available, the IEC (International Electrotechnical Commission) has gone one step further and published a publically available standard 62722 "Performance Requirements—LED Luminaires for General Lighting" [29]. This document provides the quality criteria that should be used when comparing LED products and also suggests that this information should be published on product datasheets. The criteria listed include: input power, luminaire luminous flux, luminaire efficacy, luminous intensity distribution, photometric code, CCT (correlated color temperature), CRI (color rendering index), rated chromaticity co-ordinate values both initial and maintained, lumen maintenance code, rated life in hours of the LED module and the associated lumen maintenance (Lx), failure fraction (Fx), corresponding to the rated life of the LED module in the luminaire and ambient temperature (Tq) for a luminaire. Of these, the newest and most important to designers and specifiers are chromaticity issues and how the life of an LED product is stated. LEDs have the potential to exhibit extremely long lifetimes and for that reason, LM-80-08 tests luminaires only until 6,000 h of operation [28]. Once the fitting has been tested for 6,000 h, "TM-21-11, IES Approved Method: Making Useful LED Lifetime Projections" is used to extrapolate these measurements and estimate useful life of the LED product [30]. LED lifetime is then specified in terms of parametric and catastrophic failure, to a chosen time. An example would be 50,000 h to L70F10. This would mean that after 50,000 h of operation, this luminaire will emit 70% of its initial light output and 10% of the individual LEDs within will have failed, thus meaning that the luminaire is at the end of its useful life. Again, this offers designers and specifiers the opportunity to compare LED product lifetimes on a fair basis. Chromaticity coordinates are recorded initially and every 1,000 h until completion of testing. These results will give designers and specifiers realistic information about how the color appearance of the tested LED products will vary initially and also how it will vary during the life of the product. Insisting that these test results are produced and spending time to fully understand what the results are portraying will go a long way to ensuring that better quality LED products are specified and installed, which should dispel some of the skepticism that surrounds LED installations.

If we now have an idea how to differentiate good quality LED products from bad quality LED products, where are LEDs generally applicable at present? Solid-state technology is developing at an amazing pace and recent developments have seen LED efficacies surpass that of fluorescent T5 lamps. Add to this that once light loss factors such as diffusers and louvers are considered, LED can be almost 30% more efficient. But good quality LED products are expensive, approximately two and a half to three times the equivalent T5 fluorescent fitting (at the time of writing), giving an 8 to 12 years payback period at best, in most cases. This, amongst other factors, suggests that linear fluorescent lighting remains the prime choice for general indoor lighting solutions for the moment but this may change in the near future and whole life costs should be considered. Areas within general lighting where LED is financially viable at present include architectural lighting, replacements for halogen lamps, replacements for compact fluorescent downlights and replacements for external metal halide fittings, particularly the lower Wattage (below 70 W) fittings and refrigeration and display units in supermarkets and retail outlets.

6. Lighting Controls and LENI

As already mentioned, EN 15193 [9] the European Energy Performance of Buildings Directive details a method of estimating lighting energy consumption that goes beyond maximum installed loads. LENI is a measure of the total lighting energy consumption for a given space for an entire year, divided by the area of that space. It is recorded in kWh/m^{-2} per annum and gives a realistic indication of energy consumed by a lighting installation [9]. Over the past decade, automated lighting controls have improved to become common place in building engineering. However, they are not without problems as Doyle [31] and others [20, 32] have illustrated. Ensuring user satisfaction throughout the working day requires integration of the lighting control system in an acceptable way to ensure that lights are on when needed and off or dimmed when appropriate. Gradual dimming is nearly always preferred by users as opposed to sudden switching off [20, 32], which can be distracting for people using the space. Dimming without override facilities often results in user dissatisfaction [20, 32].

For the future, however, it may become normal for individuals to have control of their own lighting. Technology is already moving in this direction. LED luminaires are already easily dimmed and can change spectrum and light distribution on demand. Developments in wireless communication and computing power are making it possible for a regular array of luminaires to be adjusted to provide occupants with their preferred illuminances at minimum electricity consumption, and doing this without moving luminaires when workstations are moved [33]. The concept of plug and play lighting cannot be far away [12]. But will this cause chaos, or will it be an improved solution comparable to automated controls? There is already evidence to suggest that giving individuals control improves occupant satisfaction. Different people prefer varying illuminances for the same task. It has also been established that those buildings with most overrides are also the most energy efficient [34-39].

This means that for any chosen, automatically fixed illuminance, only a minority of occupants will experience their preferred condition. When users have their desired lighting conditions, this results in improved mood and improved judgments of environmental satisfaction [34, 37]. Additionally, improvements in mood, lighting satisfaction, and discomfort achieved by giving people individual control of their lighting are proportional to the difference between the fixed illuminance and the preferred illuminance [37]. An extensive field study [38, 39] has also shown that direct/indirect lighting suspended over each workstation and providing individual control is considered better than uniform lighting with simple switching, and it saves energy.

7. Conclusions

Standards of lighting installations are improving using criteria such as cylindrical illuminance because modeling and perception of people’s faces are improved in such an installation. Room appearance is improved with higher room reflectances and energy is used much more efficiently. But conforming to existing standards may not be enough to ensure good quality lighting. Lighting standards and recommendations need to further address appearance and establish metrics to enable this to happen.

Holistic high quality design demands increased daylight but with reduced overall energy usage in the building. This is a complicated matter and varies with location, building type, building form and building usage. Daylight from windows can also produce cross vectors of light that aid modeling and increase cylindrical illuminance and user satisfaction.

LED lamp technology is evolving rapidly and provides new LED options that must be carefully evaluated by specifiers and installers to ensure product quality and suitability.

LENI offers a means of evaluating energy consumption and is being adopted in Europe, but lighting controls can be problematic and must be integrated appropriately to user satisfaction.

This paper has drawn from literature which argues that conforming to codes and standards does not always produce good lighting and that these codes and standards need to evolve further to address room appearance issues. Perceptions of lighting are increasingly related to how people view a room and the people and objects in it, as well as illuminance on the task.

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