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Daylighting standards: Do we have the correct metrics?

***Abstract**. Daylight in buildings is important in a number of ways and can bring benefits to building users and save energy. There are a number of ways to regulate the quality of daylit environments. The paper studies the way daylight adequacy is controlled in current guidance together with other metrics that are in use. These metrics are compared to developing ideas from the world of electric lighting and a new metric to control daylight adequacy is proposed.*

Keywords: Daylight, Building Codes, Mean Room Surface Exitance.

Introduction

The provision of daylight inside the built environment is something that most building users appreciate. This situation is expressed concisely by British Standard on daylighting [1] which states: *Daylighting gives to a building a unique variety and interest. An interior which looks gloomy, or which does not have a view to the outside when this could be reasonable be expected, will be considered unsatisfactory by its users. The recommendations of this part of BS8206 recognise that a principle aim of the designer is to produce interiors which are comfortable and give pleasure to their occupants.*

Before considering daylight standards it is perhaps worth considering what are the key issues for a space lit by daylight. Traditionally theses have been:

- adequate brightness
- required illuminance
- view out
- protection against glare
- availability of sunlight

To the above list two further issues have become important more recently:

- saving energy
- the biological effects of light

The process by which daylight is recommended and regulated varies from nation to nation but in all cases the control is exercised by a combination of up to 4 types of document.

Laws: These are documents enacted by the government of a nation and usually following these documents is an imperative. However quite often laws are written in general terms and rely on other documents which may on may not be referenced.

Approved Documents: These documents are normally created for or by national governments in support of laws. These documents are used to provide the details that are not provided by laws and are often deemed to be a way by which the law can be complied with, however it is important to remember that compliance with this type of document is not necessarily an imperative, but not using approved documents may be difficult.

Standards: As yet there is no European standard for daylight, however, there are a number of national standards that cover the provision of daylight in buildings. In most cases the choice whether to follow a standard or not is up to the designer, however there are a number of instances where standards are referenced by *laws* and *approved documents*.

Guidance Documents: There are a number of books and guides that provide guidance on how to provide a good daylit environment, such documents may normally be considered to be guidance, however, many such documents and referenced either directly or indirectly by more imperative documents.

The way nations use the above types of document to control daylight is very variable and this results in daylight rules that are have different degrees of compulsion behind them. Moreover, the way that daylight control is approached can vary. The two main approaches are control of the built form where the size of window openings and other features are controlled. The other method of control is to use a set of parameters that describe the daylight in buildings. There are a number different parameters controlled in different nations and summary of what is done in a selection of nations is given in **Table 1**.

Table 1 Types of daylight control in various countries.

Nation	**Control of Built Form**	**Control of Performance**			
		Daylight	View out	Sunlight	Glare
Denmark	✓				
Estonia	✓			✓[1]	
Finland	✓				
Germany		✓	✓	✓	✓
Norway	✓	✓	✓		
Sweden	✓	✓		✓	
United Kingdom		✓	✓	✓	✓

The general trend in the control of daylight has been from the prescriptive restrictions on building form toward the adoption of performance based metrics.

One of the key parameters controlled is daylight availability and the main way that it is currently controlled is daylight factor. View out and glare are normally considered in a more subjective way. It is more straight forward to assess sun light as it is a simple matter to predict where the sun will be at a given time on a given date and if sun light will enter a building, however, there is no clear pattern to the times and dates for which sunlight is required.

Daylight Factor

[1] In Estonian Building Act of 1992 but replaced in 2000

The concept behind daylight factor is that it is the ratio of illuminance at point inside a building to the illuminance received at an unobstructed point outside. This is a nice concept but its weakness is that it is necessary to assume a fixed light distribution from the sky or there can be no single value for daylight factor, usually is the overcast sky that is used to calculate daylight factor. Most regulations that rely on daylight factor require it to be evaluated at a number of places across a nominal or working plane within a room with in some cases an average value being used.

Over recent years people have looked at the basic daylight factor concept and tried to improve on it. One of these improvements was the concept of median daylight illuminance (MDI). This concept was developed so that daylight could be meaningfully specified across a range of different climates. MDI for a building at any given site can be calculated by multiplying the daylight factor by the median external illuminance. The median external illuminance is defined as the illuminance at an unobstructed site due to daylight that is exceeded for 2,190 hours per year.

Daylight factor in many ways is a good parameter to use control building performance in so far as the simplifications that underpin the concept make it being relatively easy to calculate. It is also possible to make an assessment of daylight factor by measurement but you do have to be carful in selecting the daylight conditions when you do.

However, the limitations imposed by daylight factors use of the overcast sky has led a number of people to advocate a move to Climate Based Daylight Modelling (CBDM).

Climate Based Daylight Modelling

CBDM [2,3] operates by taking a climate file for given site which gives a typical year of hour by hour values for solar radiation and using it to predict the luminance distribution of the sky at that time. This sky distribution is used in a lighting simulation package such as RADIANCE [4] and the result is an illuminance value at each point of interest for each hour or part of hour during the year. Naturally this process creates a lot of numbers and so it has been necessary to invent some new metrics to summarise them. The most commonly used metric for this is useful daylight illuminance (UDI). The definition of UDI changes from time to time but most people would take it as the fraction of the time that the point receives a daylight illuminance in the range 100 to 3,000 lux.

CBDM has been developed almost exclusively to look at the amount of daylight received by a working plane. This can be quite useful if you are wanting to calculate the energy required by an electric lighting system that is supplementing the daylight to provide light on visual tasks arrange at a given height in a room.

Electric Lighting Practice

Many years ago, electric lighting was specified as an average illuminance across a working plane. However, this was a wasteful practice as it was necessary to provide relatively high levels of illuminance the whole room even if the visually demanding tasks that required this illuminance were only taking place over relatively small areas of the working plane. In 2002 with the publication of EN 12464-1 [5] the concept of the working plane was deleted from approved European lighting practice. Instead of lighting the working plane it became only necessary to light task areas. To ensure that this did not lead to small pools of light and areas of darkness there were rules to ensure that the areas around the task areas were illuminated. These rules have been built on with time and in the 2011 edition of EN 12464-1 there are a number of parameters that control the lit environment to ensure a good visual environment, these include:

- reflectance of and illuminance on room surfaces
- illuminance on the areas immediately surrounding task areas
- illuminance on background areas
- mean cylindrical illuminance
- modelling

As the provision of task illuminance becomes less important with the adoption of self luminous devices in many work environments the parameters listed above become the key drivers of electric lighting design. In is therefore interesting to ask the question can these or similar parameters by used to specify daylight?

Mean Room Surface Exitance

Cuttle [6] proposed that one the key elements in any lighting design should be that the occupants of a room should perceive the space to be adequately illuminated. Cuttle argues that the concept of perceived adequacy of illumination (PAI) explains why most codes around the world set the illuminances targets way above anything that could be justified by the tasks being carried out.

Cuttle also argues that the lighting metric that is best correlated with PAI is mean room surface exitance (MRSE). The exitance of surface is quantity of flux leaving the surface divided by its area, as exitance is expressed in lumens per square meter it has the unit lux. The use of MRSE is not totally at odds with lighting practice specified in the current edition of EN12464-1 where recommendations for illuminance on walls and ceiling coupled with guidance of surface finishes effectively forces a minimum surface exitance.

MRSE turns out to have a quite a few nice properties as a metric. Firstly it is relatively easy to calculate to a first approximation using Sumpner's principle [7]. Formula (1) applies Sumptner's principle to calculate MRSE

(1) $$MRSE = \frac{QR}{A(1-R)}$$

Where Q - the total flux entering a room, A - the total area of the room surfaces and R - the average reflectance of the room surfaces. The MRSE of a room also set the indirect illuminance received by persons eye in the room which has a value equal to MRSE and the average room luminance is equal to the MRSE divided by π. With this connection between MRSE and average luminance it becomes clear that average retinal illuminance is also a function of MRSE and this potentially gives a physiological reason why MRSE is correlated to PAI.

Biological Effects of Light

Over the past ten years or so there has been significant interest in the impact of light on various aspects of human physiology and psychology that are not associated with vision. There is a good summary of this work by Lucas et al [8]. One key aspect of the research into the biological effects of light has been the discovery of the intrinsically photoreceptive retinal ganglion cells (ipRGCs) in the human retina. These cells are a new type of photoreceptor and they appear to be distributed across the retina. Much effort has been put in to studying the spectral sensitivity of these cells and various action spectra have been proposed. However, there has been very little work put into the evaluation of the impact of the spatial distribution of light necessary to best deliver biological impacts.

Given the relatively uniform distribution of the igRPCs across the retina then it is likely that the human biological response to light may be correlated to average retinal illuminance. Thus it is likely that MRSE is a good metric for lighting in a room if we want to assess how effective the lighting is at producing a biological impact.

MRSE and Daylight

In the above sections the argument has been made that MRSE is a good metric to describe the lighting in a room both from a perspective of people thinking that the space is well lit but also is it may well correlate with the biological impact of the lighting. Also the concept of the working plane has gone from standards that specify electric lighting in Europe. Thus it is necessary to question the use of working planes in the control of daylight.

Changing daylight metrics away from a focus on the working plane and the adoption of a metric based on MRSE also has a number of other advantages the most notable of which is simplicity. MRSE is a single number at any given time and so it would be simple to develop a MRSE factor that related the MRSE in a room to external illuminance. Or it could be calculated as part of CBDM type process and perhaps the Median MRSE could prove to be a useful parameter. Another benefit of the use of MRSE is the fact that there is a simple calculation approximate calculation process for it. In formula (1) the term Q is defined as the total flux entering the room. It is a simple matter to evaluate this for a given window as it will be the illuminance received by the window multiplied by the area of the window multiplied by the transmittance of the window.

Conclusion

There are lot of different ways in which daylight is currently controlled. Any further development in standardisation to control daylight has to consider what metrics best correlate to the benefits that daylight can bring, however at the same time any metric must be simple to use.

In this paper it has been argued that a metric based on MRSE may well be a better alternative to metrics based on light hitting a working plane, moreover MRSE is a simple metric to work with.

As well as MRSE there are a lot of other candidate metrics that have been proposed. Some of these are quite complex to work with such a cubic illuminance [9] across the volume of space. There are some metrics that are only useful in a restricted set of circumstances such are target ambient illuminance ratio [10] which is only really useful when designing the lighting in a sculpture gallery or similar situation where the modelling of form is critical. Moreover, both cubic illuminance and target ambient illuminance ratio are easy to calculate for daylight situations as was recently demonstrated by Guan [11]. However, the general principle should be that no metric developed for electric light should be automatically rejected from use in daylighting.

In summary there are a number of new metrics that may well prove to be useful in the specification of daylight. In particular MRSE appears to have the potential to be a metric that is many ways better that our current metrics that are based on the illuminance received by a working plane. However, it is acknowledged that being a better is not enough to get a metric adopted. This is because any new standard or other control document must be based on metrics where people have some experience of their use. Moreover, it is necessary to understand the consequences for building design if the new metric was adopted. Thus it necessary for the lighting community to look beyond current specified practice and experiment with new metrics, as without this we are destined never to improve lighting practice.

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