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‘Climate connectivity’ in the daylight factor basis of building standards

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ABSTRACT

This paper describes a proposal for a daylight standard for CEN countries. It is now widely accepted in the research community, and increasingly so amongst practitioners, that the standards/guidelines for daylight in buildings are in need of upgrading. The essence of the proposal is that the ‘target’ for daylight provision should be founded on the availability of daylight as determined from climate files. The proposal is in fact a refinement of an approach originally described in a CIE document from 1970, and which appears to have been largely overlooked since then. The proposal states that a design should achieve a target daylight factor at workplane height across a specified percentage of the relevant floor area for half of the daylight hours in the year, where the target daylight factor is based on the provision of 300 lux. A key feature of the refinements are the formulation of the methodology such that the likelihood for misinterpretation and ‘game-playing’ is greatly reduced, if not eliminated altogether. The method, founded on cumulative diffuse illuminance curves, could be introduced relatively swiftly since it requires only modest enhancement of existing daylight prediction tools. In addition, the proposal will provide a sound ‘footing’ for eventual progression to evaluations founded on full-blown climate-based daylight modelling.

1. Background

By the late 1800s the pressure to accommodate an increasing number of people in the cities of the developing world led to taller and more tightly-packed building forms, thereby reducing and often eliminating entirely the direct view of sky from much of the useable, internal space. This in part led to the need for some objective measure of the daylighting performance of a space which could, if required, function as a tool to evaluate buildings at the planning stage. Daylight was at that time still the preferred source of illumination for both manual and clerical work – it was also ‘free’. The work of Nordhaus has shown that the real cost of artificial light has dropped by nearly four orders of magnitude over the last two hundred years [1].

It is only over the last decade or two that we have come to appreciate once again the true importance of ‘good’ daylighting design for buildings. However the legacy of many years of effective downgrading of daylighting in the overall consideration of building design is still apparent today. Many standards for daylighting have hardly changed over 40 or more years, and often make no account of the actual availability of daylight. Attempts to progress matters have often resulted in less than satisfactory outcomes, e.g. vague or confusing criteria and/or methodologies. For example, the various ‘clear sky options’ recommended in both LEED and ASHRAE have resulted in approaches that are one or more of the following: confusing, inconsistent, prone to the vagaries of patterns in climate data, and/or without a proven rationale [2].

There is in effect an “impasse” that is hindering any progression towards standards that are founded on actual daylight availability [3]. It should also be pointed out that any attempt to create a standard based on objective criteria is going to be difficult, the complexity of the situation was made clear by Boyce [4] and the level set in any standard is going to be as much about what is economically possible as much as it is about what is technically necessary. A way around that impasse was proposed in the course of deliberations of the panel for CEN Technical Committee 169/WG11 ‘Daylight’. This paper shows how the proposal could form the basis of a reliable and effective EU daylighting standard. It is possible for guidelines produced in one country to become *de facto* standards elsewhere if they are adopted locally. One example is the Building Research Establishment Environmental Assessment Method (BREEAM) which has been taken up and promoted in a

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number of EU countries and beyond. The BREEAM recommendations for daylighting allow several approaches, some of which appear to accommodate a measure of local daylight availability using latitude as a proxy. This paper will make the case that the proposal made to CEN TC 169/WG11 offers a basis for an EU-wide standard that is more robust than BREEAM, has greater clarity, and is less prone to wilful or accidental 'game-playing'.

1.1. The daylight factor

The origins of the daylight factor (DF) are actually somewhat hazy since there does not appear to have been a seminal paper introducing the approach. The reference to its first suggestion in 1895 appears to be anecdotal and recalled a number of years later [5]. The daylight factor was conceived as a means of rating daylighting performance *independently* of the actually occurring, instantaneous sky conditions. Hence it was defined as the ratio of the internal horizontal illuminance E_{in} at some arbitrary point in a space to the unobstructed (external) horizontal illuminance E_{out} from a hemisphere of sky. Light from the sky can arrive at a point in a space directly if any sky is visible from that point, and also indirectly following one or more reflections from surfaces inside and outside of the space, Fig. 1. The daylight factor is usually expressed as a percentage:

$$DF = \frac{E_{in}}{E_{out}} 100\% \tag{1}$$

However, the external conditions still need to be defined since the luminance distribution of the sky will influence the value of the ratio. At the time that the daylight factor was first proposed it was assumed that heavily overcast skies exhibited only moderate variation in brightness across the sky dome, and so they could be considered to be of constant (i.e. uniform) luminance. Measurements revealed however that a densely overcast sky exhibits a relative gradation from darker horizon to brighter zenith; this was recorded in 1901. With improved, more sensitive measuring apparatus, it was shown that the zenith luminance is often three times greater than the horizon luminance for some of the most heavily overcast skies [6]. A new formulation for the luminance pattern of overcast skies was presented by Moon and Spencer in 1942, and it was adopted as a standard by the CIE in 1955. Thus, since 1955, the daylight factor is strictly the ratio of internal illuminance to unobstructed (external) horizontal illuminance determined under a sky luminance distribution that conforms to (or is taken to be) the CIE standard overcast sky pattern:

$$L_\theta = \frac{L_z(1 + 2\sin\theta)}{3} \tag{2}$$

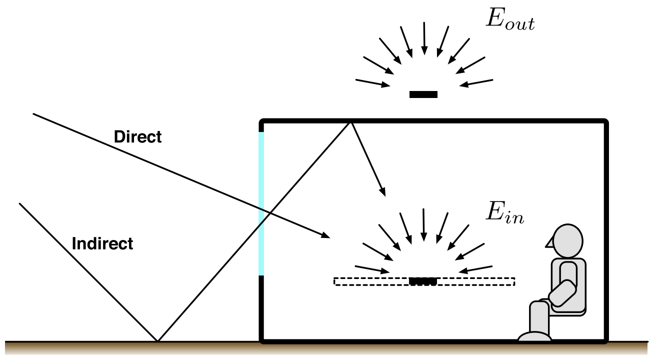

Fig. 1. Definition of the daylight factor.

where L_θ is the luminance at an angle θ from the horizon and L_z is the zenith luminance. Notwithstanding the recent questionings regarding the validity of the CIE standard overcast pattern as the sole basis for the quantitative evaluation of daylight [2], it remains the most commonly used sky luminance pattern in guidelines and recommendations.

1.2. The average daylight factor

The average daylight factor (ADF) equation was first proposed by Lynes in 1979 [7]. In the original formulation the ADF calculated was that for all the enclosing surfaces of the space. The equation was revised by Crisp and Littlefair in 1984 following validation tests using scale models [8]. In the revised version the ADF calculated is that for the working plane only – it is usually expressed as follows:

$$\overline{DF} = \frac{TW\theta M}{A(1 - R^2)} \tag{3}$$

Where $\overline{DF}$ is the average daylight factor; T is the effective transmittance of the window(s); W is the net area of window(s); θ is the angle in degrees subtended in vertical plane by sky visible from the centre of a window; M is the maintenance factor; A is the total area of bounding surfaces of the interior; R is the area-weighted mean reflectance of interior bounding surfaces.

Consider the single and double aspect glazing arrangements for the 6 by 9 by 3.2 m space (W× D× H) shown in Fig. 2. Using typical room reflectance values, the ADF calculated using the above equation is 4.9% – the same of course for both glazing arrangements. The ADF value predicted using (the rigorously validated) *Radiance* program is 5.2% for the single aspect space and 4.7% for the double aspect space. Notwithstanding the fact that the modified ADF equation was calibrated against measurements in scale models, where the inaccuracies are known to be considerably greater than the ± 10% demonstrated for the *Radiance* program, the agreement is reasonably good. However, that is not the issue – what of the differences in daylight factor *distribution* for the two spaces? Whilst the spaces have the same ADF – as predicted by equation (3) – the distributions in daylight factor are markedly different.

This illustration also highlights the inadequacy of using an average value for the daylight factor – even when determined from a grid of points. Table 1 gives the average and median DF values for the two spaces shown in Fig. 2. The simulated DF values in parentheses are those predicted with a 0.5 m perimeter gap between the sensor grid and the walls as recommended in LG5 [9]. The green rectangle superposed on the DF distributions in Fig. 2 delineates the 0.5 m perimeter gap. For side-lit spaces the average is always greater than the median, especially so for single aspect glazing: 5.2% and 2.3% respectively. The average value is more open to game-playing than the median – note how the median is largely unchanged whether or not the LG5 guidance is followed. The median also is far more revealing about the luminous environment because it informs on the spatial distribution of the daylight factor: half the points will be above the median and half will be below. Notice that, not only is the difference between the single and dual aspect median values (2.3% vs. 3.3%) much greater than the difference in the ADF (5.2% vs. 4.7%), but the sense is reversed: the single aspect ADF is greater than the dual, but the dual aspect median DF is greater than that for the single aspect space (Table 1). Based on ADF alone, the single aspect space would be deemed to be *'better'* than the dual aspect. Notwithstanding its appealing ease and simplicity, the ADF cannot make any distinction between single and multi-aspect window designs (having the same glazing area for vertical windows). This would appear to be a fundamentally

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