A PROPOSAL FOR A EUROPEAN STANDARD FOR DAYLIGHT IN BUILDINGS

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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 fraction 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, Figure 1 [11].

It is only over the last decade or two of the period shown in Nordhaus' plot 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.

This paper is the third in a series on daylighting standards. The first paper gave an

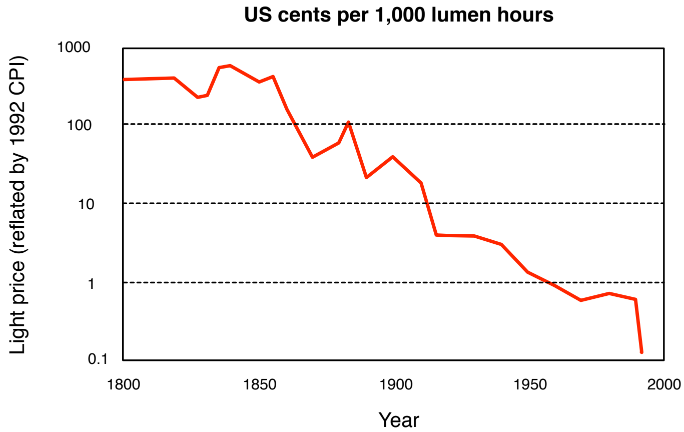

Figure 1: Real cost of artificial light in US cents per 1000 lumen hours, reflated for the 1992 consumer price index (redrawn from Nordhaus [11])

overview of developments in the formulation of guidelines since the precursor of the daylight factor was first postulated by Alexander Pelham Trotter back in 1895. That paper argued that the recently made attempts to advance beyond the daylight factor (e.g. various 'clear sky options') 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 [8].

The second paper developed and expanded the critique of daylighting standards [9]. It also described what is in effect an "impasse" that is hindering any progression towards standards that are founded on actual daylight availability – which surely should be the foundation of guidelines, recommendations, etc. 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 [1] 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 EU 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 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 TC 169/WG11 offers a basis for an EU-wide standard that is, we believe, 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 are actually somewhat hazy since there does not appear to have been a seminal paper introducing the approach. The reference to its introduction in 1895 appears to be anecdotal and recalled a number of years later. 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} to the unobstructed (external) horizontal illuminance E_{out}, 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 [10]. 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 to external illuminance determined under a sky luminance distribution that conforms to the CIE Standard overcast sky pattern:

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

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 [8], it remains the most commonly used sky in guidelines and recommendations.

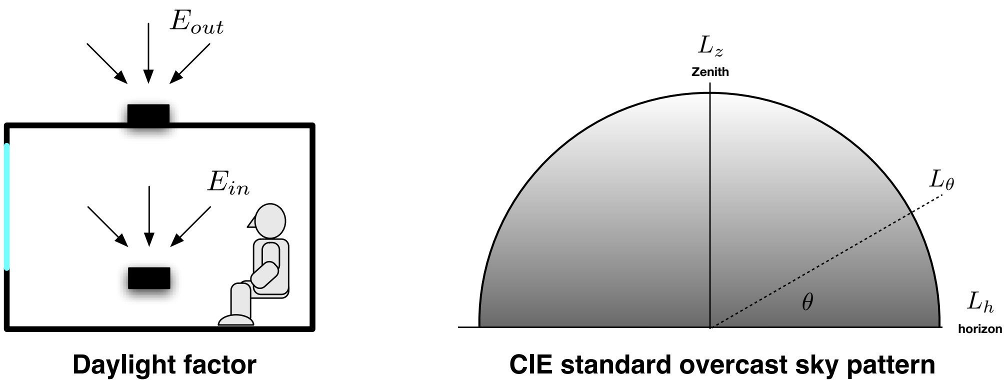

Figure 2: Definition of the daylight factor

1.2 Climate-based daylight modelling

The accurate prediction of daylight in spaces under realistic sun and sky conditions, and for many instances, e.g. hourly for a full year, was first demonstrated in the late 1990s [6][13]. Now known as climate-based daylight modelling (CBDM), it is the prediction of luminous quantities founded on standardised meteorological files specific to the locale for the building under evaluation. CBDM delivers predictions of, say, internal illuminance on an hourly (or shorter) basis for a full year, accounting for the contribution from varying sun and sky conditions. Thus it models daylight how it is experienced: holistically – the illumination effect of sun and sky together. CBDM is over a decade old and has been used effectively on a number of projects large and small, e.g. from the New York Times Building to residential dwellings. Metrics founded on CBDM include useful daylight illuminance (UDI) and daylight autonomy (DA). A CBDM metric was approved by the US Illuminating Engineering Society in 2012 [4]. Called spatial daylight autonomy (sDA), the 'target' is based on the attainment of 300 lux for 50% of the analysis period (08h00 to 18h00 local time) across 55% or more of the floor area to be considered "nominally acceptable", and 75% or more of the floor area to be rated "favourably" or "preferred".

Notwithstanding that it is over a decade since CBDM was first demonstrated, and its effectiveness subsequently proven on a variety of 'real world' projects, daylight criteria in most guidelines and recommendations are still founded on the daylight factor. More recently there have been attempts to advance the DF method incrementally using so-called 'clear sky' evaluations, though these appear unsatisfactory for reasons given in first of this series of papers [8]. For reasons articulated in the second paper of this series, it seems unlikely that a smooth transition to climate-based modelling could be effected without first shifting the basis of existing evaluations to absolute levels of illuminance, i.e. lux [9]. However, before describing that proposal, we shall first examine the BREEAM daylight recommendations since they appear to be gaining in popularity in Europe and further afield.

2 THE BREEAM DAYLIGHT RECOMMENDATIONS

The Building Research Establishment Environmental Assessment Method (BREEAM) guidelines describe two ways in which compliance can be demonstrated in order to attain the single credit available for daylighting. The criteria available are based on either "daylight factor" or "daylight illuminance":

- **Daylight factor (DF)** – achieve a minimum average daylight factor across 80% of the "relevant area" at working plane height.
- **Daylight illuminance (DI)** – achieve an average of at least 200 lux for 2,650 hours per year or more, and also at least 60 lux for 2650 hours per year or more at the "worst lit" point (in both cases across 80% of the "relevant area" at working plane height).

The specified average daylight factor (DF) values depend on the latitude of the building and are shown in the column labelled "First credit" in Table 1. They range from 1.5% for latitudes less than 40° to 2.2% for latitudes greater than or equal to 60°, i.e. a range of 0.7% in average DF. The two "exemplary" columns are present in the version of the guide distributed by the Norwegian Green Building Council called BREEAM NOR. Designs achieving those values are awarded an "innovation credit". For single storey buildings the exemplary DF is twice the "First credit" DF and for multi-storey it is one and a half times that. The following supplementary information is given:

> *The average daylight factor ... [is] intended for use in temperate and cool climates with a significant percentage of overcast or cloudy skies. For hot or sunny locations with predominantly clear skies, especially those at latitudes much less than 40 degrees, it is better to use the daylight illuminance criteria instead. The daylight illuminance calculation should include the additional light available from clear and partly cloudy skies and reflected sunlight.*

This implies – but does not state explicitly – that the building should be simulated using climate-based daylight modelling techniques [7]. Similar to the DF criteria, BREEAM NOR has higher "exemplary" targets for the DI criteria of 400 lux and 300 lux for single- and multi-storey respectively (for 2,650 hours of the year). As with the DF "exemplary" targets, the DI exemplary targets are simply 2× and 1.5× the single credit value.

Table 1: BREEAM DF criteria with "exemplary" values from BREEAM NOR

	Average daylight factor [%]		
Latitude	First credit All buildings	Single-storey (exemplary)	Multi-storey (exemplary)
$\leq 40°$	1.5	3	2.25
40–45°	1.7	3.4	2.55
45–50°	1.8	3.6	2.7
50–55°	2.0	4.0	3.0
55–60°	2.1	4.2	3.15
$\geq 60°$	2.2	4.4	3.3

2.1 Example application of BREEAM

When considering a single space, the BREEAM guides do not specify precisely *where* the 80% of the total area used in the evaluation should be. For example, with a side-lit space which has glazing on one facade wall the outcome of the evaluation can be very sensitive to the placement of the sensor plane when it does not cover the entire area. The top-left image in Figure 3 shows a 3D rendering of a simple 6m wide by 9m deep side-lit space. The graphic below shows the DF distribution at workplane height (0.8m) across the entire 6×9m internal plan. The three images on the right show possible placements of the 80% area: 'front' (i.e. adjacent to the window); 'middle' of the space; and, lastly at the 'back' of the space. The maximum, average, median and minimum DFs for the four cases (i.e. entire area and three possible locations for the 80% section) are given in Table 2.

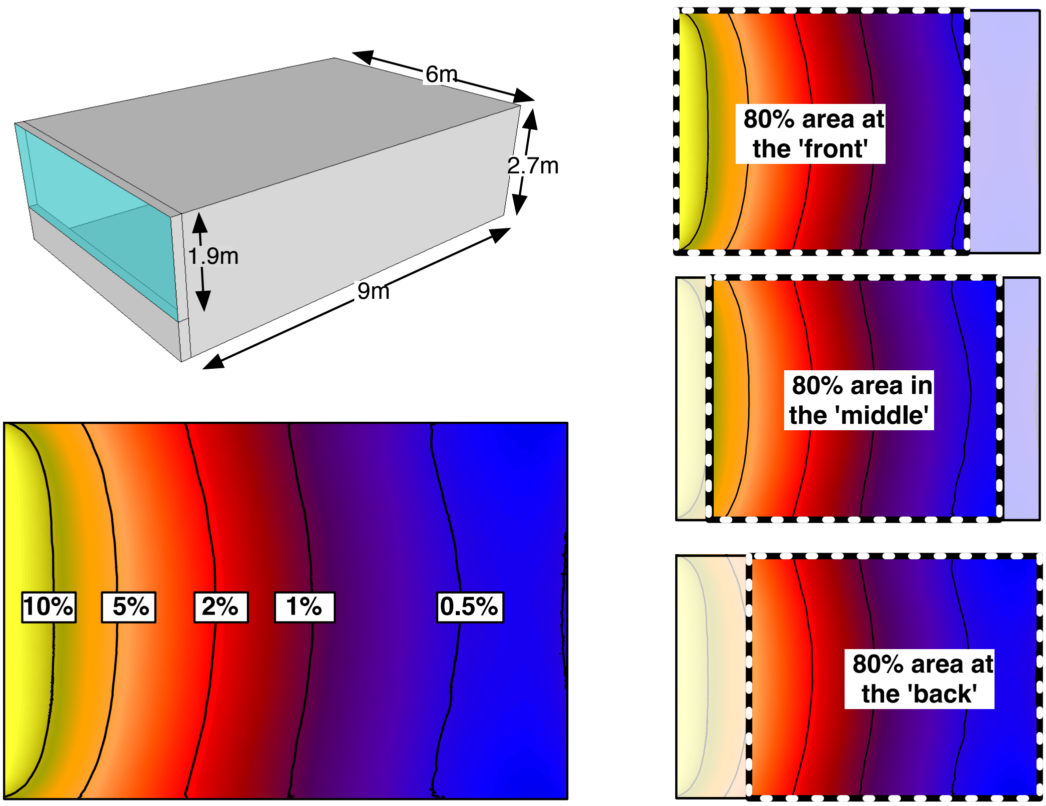

Figure 3: Daylight factors across a 9m by 6m side-lit space

The average DF for the entire area is 2.81%. however, immediately apparent is the marked sensitivity of the average DF to the placement of the 80% section: 3.41%; 2.00%; and, 1.26% when the 80% area section is located at the 'front', 'middle' and 'back' respectively (Table 2). Thus, if the section were located at the front, the average DF of 3.41% would be sufficient to qualify the space for the 'multi-storey exemplary' at <u>all</u> latitudes. However, if placed in the 'middle', then the space would achieve only just achieve the 'first credit' for latitudes up to 55° and <u>none</u> in the 'multi-storey exemplary' category.

Table 2: DF metrics for the 6m×9m space shown in Figure 3

Area	Daylight factor [%]			
	Maximum	Average	Median	Minimum
All 100%	15.2	2.81	1.11	0.38
Front 80%	15.2	3.41	1.65	0.46
Middle 80%	9.4	2.00	1.11	0.39
Back 80%	5.0	1.26	0.80	0.38

2.2 The compliant area

Strictly speaking, the evaluation described above applies only to a single space. When the evaluation if for multiple spaces – as will often be the case – then the rationale for assessment of the ensemble of spaces is as follows:

> *Where the compliance requirement specifies that a percentage of floor area must be adequately daylit, it refers to the percentage of the total floor area of all the rooms that must be assessed, i.e. the compliant area. If, for example, a development has 6 rooms that must be assessed, each 150m^2 (total area 900m^2) and 80% of this floor area must meet the criteria, then 720m^2 must comply with the criteria; this is equal to 4.8 rooms. The number of rooms that must comply must always be rounded up; therefore, in this example, five rooms must have an average daylight factor of 2% or more (plus meet the other criteria) to achieve the credit.*

This guidance we find to be lacking somewhat in clarity. In the example given in the aforementioned quote, it would appear that the sixth space has *no requirement whatsoever for daylight*, even though it could be of the same type (e.g. occupied office) as the other five spaces. Furthermore, does the guidance indicate that, for the five spaces in the example that need to comply, the area considered should be 100% of each individual office space? In which case, the sensor plane will invariably be close to the window resulting in elevated average DF values, e.g. 2.81% for the space shown in Figure 3. Given that school classroom units have been prefabricated to apparently conform to the BREEAM guidelines [9], it would seem that these were designed to have an average DF of 2% (for typical UK latitudes) across, one assumes, 100% of the space area. Unless perhaps each unit can somehow count as in individual "development", in which case it would be an average DF of 2% across 80% of the space area. Furthermore, it seems quite possible that a practitioner might overlook the "Compliance Note" on "Percentage of assessed area" (page 67 in the guide) and take the information in the table on daylight factors (page 71 in the guide) as complete.

The 2011 revision of Lighting Guide 5: Lighting for Education recommends that there is a 0.5m border width (i.e. perimeter) between the sensor points and the walls/glazing [5]. For the 6m×9m space shown in Figure 3, the LG5 perimeter recommendation equates to 74% of the useable floor area. Also note that, the median DF for a space is largely insensitive to the size of a perimeter. The median value informs on the spatial distribution of the DF whereas the average value does not. Thus, the median DF would appear to be a much sounder basis for standards, guidelines, etc. than the average DF. Note also that, for side-lit spaces, the median DF will always be markedly less than the average DF (Table 2).

2.3 Climate and daylight in BREEAM

The average DF target in BREEAM depends on latitude for the space under evaluation, ranging from 1.5% (lat$\leq$ 40°) to 2.2% (lat$\geq$ 60°). Evidently, this is intended to make account of the prevailing lower levels of daylight illuminance at higher latitudes. The authors are not aware of the basis for the actual DF values given in Table 1, though the general rationale appears sound. This suitability of the relation between average DF and latitude is partially assessed in a later section.

As noted, the daylight illuminance (DI) criterion implies that climate-based daylight modelling is used to test for compliance. The target for DI is in fact a variant of Daylight Autonomy (DA). Though the specified illuminance (200 lux) and occurrence (2,650 hrs) are quite different from the values given in the IES approved method [4]. Furthermore, a recent study by Reinhart and Weissman showed that a high occurrence 300 lux correlated well with student assessments of a 'well daylit' space [14].

Of greater concern regarding the DI criterion is the lack of clarity, and the potential for users of the approach to interpret differently the guidance. For example, as noted above, the guidelines advise that the: *"daylight illuminance calculation should include the additional light available from clear and partly cloudy skies and reflected sunlight"* [2]. But nothing explicit about a criterion for direct sunlight, nor any guidance about how the simulation should be carried out. If sunlight is included in the simulation, then should the operation of shading devices (e.g. blinds) also be accounted for? A vital consideration since the outcome will be highly dependent on the absence or presence of blinds/controls. In light of these concerns, we believe that current advice for the DI criterion is incomplete, open to interpretation and potentially leading to either accidental or wilful 'game-playing' regarding the outcome.

3 THE PROPOSAL MADE TO TC169/WG11

The daylight in an interior space depends, firstly, on the availability of natural light (i.e. the prevailing climate at the site) and, thereafter, the properties of the space and its surroundings. Thus the evaluation of the provision of internal daylight should make account of the availability of daylight at the site in addition to accounting for the properties of the space [3]. It is proposed to change the basis of daylight evaluation in standards from relative values based on a single sky (i.e. the DF), to the annual occurrence of an absolute value for illuminance (i.e. lux) estimated from the cumulative availability of diffuse illuminance as determined from climate data, e.g. standardised climate files. This is an application of an established but largely neglected approach [3]. This proposal offers several advantages. Firstly, since the estimate is derived from daylight factors, it requires only a modest enhancement to existing software tools that predict DFs. Next, although not CBDM, the approach nevertheless provides some 'connectivity' to the prevailing climate.

The proposal is as follows. To demonstrate compliance with the standard, it is necessary to show that a target illuminance E_T is achieved across a percentage of the relevant floor area A_P for a fraction of the year Y_F. Internal illuminances are derived from annual data for diffuse horizontal illuminance appropriate to the location of the building/space under evaluation. In the following sections we describe the rationale for selecting values for the parameters E_T, A_P and Y_F.

3.1 The target illuminance E_T

A number of studies have demonstrated that 300 lux of natural illumination is considered adequate by the majority of building users and also correlates with the notion of a "well daylit space" [14][4]. In the 1970 CIE report 'Daylight', 300 lux is described as suitable illumination for *"prolonged office work"* [3]. Additionally, design levels for artificial lighting are increasingly being set at or close to the 300 lux mark. Studies have revealed that the 'switch-on' probably for electric lighting is high for illuminances less than 100 lux and very low for illuminances 300 lux or greater [12]. Thus we propose that the target illuminance should be 300 lux.

The target illuminance is derived from the cumulative availability of (unobstructed external) diffuse illuminance H as determined from standardised or similar climate files. The criterion to select and aggregate values from the annual diffuse illuminance time-series is described in a following section. For now we simply need to note the relation between the target illuminance E_T, the target external diffuse horizontal illuminance H_T and the target daylight factor D_T:

$$\frac{E_T \times 100}{H_T} = D_T\% \tag{3}$$

This is of course just Equation 1 with different symbols. In other words, for a given external diffuse horizontal illuminance H_T, a daylight factor of $D_T\%$ is needed to produce an internal illuminance of E_T (i.e. of 300 lux).

3.2 The percentage of the relevant floor area A_P

The percentage of the relevant floor area should depend on the potential for the space to deliver daylight to the interior. The most typical is the multi-story side-lit space with windows on just one facade. For this type of space we propose that the target illuminance of 300 lux is achieved across 50% of the floor area (for the fraction of year Y_F). For multi-aspect glazing the value should of course be greater. Though care will be needed in the specification and indeed wording of any guidelines since it is possible to inadvertently discourage modest improvements in daylighting that fall short of the higher specification for, say, spaces with glazing on two facades. For example, say that the percentage of the relevant floor area for twin aspect daylighting was 75%. For spaces where only small additional windows are practicable on the second facade, it might not be possible to achieve the area target of 75%, and so the space would meet the more onerous criterion. In which case, the designer might well decide to revert back to just having the main glazing on one facade. These unintended consequences are difficult if not impossible to avoid in any incremental rather than sliding-scale system of 'reward'.

Top-lit spaces are perhaps more straightforward in this regard, and the percentage area target should be fairly high, e.g. 80% or 90% of the occupied floor area. However, targets for spaces with multi-aspect glazing, 'borrowed light' from atria, sloped-facade windows, etc. require rather more consideration. The determination of practicable percentage area targets for these various space/building types, and the formulation of a rating system that avoids unintended consequences, are work that is yet to be done.

3.3 The fraction of the year Y_F

There are a number of ways to select a fraction of the year for the evaluation of daylight provision. The selection criteria we tested were of four types:

- A fixed period of the day, e.g. 'typical' working hours. For many latitudes this would include hours of darkness in winter.

- Based on sun position, i.e. as a proxy for daylight availability. The condition could be any arbitrary sun altitude ≥0°.
- Based on diffuse horizontal illuminances that exceed a threshold, i.e. only those instances where a specified level of (external) daylight has been achieved.
- Based on a fixed proportion of the illuminance values in the climate dataset.

In order to make meaningful comparison between the different criteria, we decided to compare the median value for the diffuse horizontal illuminance determined for each of the tested criteria. To further ease the comparison, we converted the median diffuse horizontal illuminance into a target daylight factor using Equation 3, where $E_T = 300$ lux i.e. the target illuminance value. In other words, whatever the selection period according to the various criteria, we determined the daylight factor required to deliver 300 lux for half of that period.

We tested the outcomes for eight European locations covering a wide range in latitude and prevailing climate type, Table 3. The climate files (freely available) were downloaded from the EnergyPlus website. The last column in Table 3 gives the number of "sunny" days for each of the climate files. A sunny day was taken to be one where more than half of the daily total of global horizontal illuminance was due to direct solar radiation. This quantity varied from 49 days (Moscow) to 194 (Madrid).

Table 3: The eight climate files used in the sensitivity study

ID	City/ Station	Country	Latitude	Longitude	"Sunny" days
DEU-Hamburg	Hamburg	Germany	53.63	-10.00	50
ESP-Madrid	Madrid	Spain	40.38	3.68	194
FRA-Paris	Paris	France	48.87	-2.40	64
GBR-London	London	UK	51.50	0.18	71
ITA-Rome	Rome	Italy	41.90	-12.50	107
POL-Warsaw	Warsaw	Poland	52.23	-20.97	53
RUS-Moscow	Moscow	Russia	55.75	-37.63	49
SWE-Ostersund	Ostersund	Sweden	63.18	-14.50	59

We tested the following conditions: four fixed periods of the day; three sun altitude; three external diffuse horizontal; and, one fixed proportion of the total year. The results are give in Table 4. Taking the first group, it is evident that, as the period of the day included in the evaluation starts earlier and finishes later, the target daylight factor required to deliver 300 lux (for half of the evaluated period) increases. This, of course, is because a greater number of hours of darkness and low daylight availability are included in the assessment as the evaluated day length gets longer. Note also that the range in target daylight factor increases also. With increasing minimum sun altitude the sense of the previous trend is, of course, reversed. Similarly for increasing the minimum diffuse horizontal illuminance included in the evaluation. For the last case we simply take the highest 4,380 values of diffuse horizontal illuminance from the climate data (i.e. exactly half) and determine the D_T from the median of that sample.

Considering now the results as a whole, the following observations are made. The application of selection criteria based on a fixed period of the day applied uniformly across Europe may be less than ideal for a number of reasons. Firstly, periods of occupancy vary depending on building use and location, also, intended use could change after the building

Table 4: Sensitivity of 300 lux target daylight factor value to various criteria

Criteria	Climate file ID / Target daylight factor D_T [%]								Rng
	DEU	ESP	FRA	GBR	ITA	POL	RUS	SWE	D_T%
09h $\leq$ h $\leq$ 16h	1.76	1.73	1.72	1.83	1.41	1.61	1.73	2.24	0.83
08h $\leq$ h $\leq$ 17h	2.03	1.84	1.92	2.04	1.57	1.81	1.99	2.52	0.95
08h $\leq$ h $\leq$ 19h	2.19	1.84	1.99	2.17	1.77	2.07	2.16	2.75	0.98
07h $\leq$ h $\leq$ 20h	2.70	2.09	2.33	2.66	2.12	2.56	2.70	3.32	1.23
Sun alt $\geq 0°$	2.17	1.78	1.95	2.19	1.78	2.09	2.11	2.58	0.80
Sun alt $\geq 1°$	2.10	1.75	1.90	2.14	1.75	2.04	2.01	2.47	0.72
Sun alt $\geq 5°$	1.91	1.67	1.75	2.01	1.65	1.83	1.83	2.02	0.37
$E_{dh} \geq$ 200 lux	2.09	1.76	1.89	2.13	1.73	2.00	2.03	2.49	0.76
$E_{dh} \geq$ 500 lux	2.04	1.75	1.85	2.09	1.69	1.95	1.98	2.41	0.72
$E_{dh} \geq$ 1,000 lux	1.97	1.72	1.80	2.05	1.67	1.90	1.92	2.32	0.65
Median 4,380 hgst.	2.16	1.77	1.94	2.17	1.77	2.07	2.09	2.55	0.78

is evaluated. Furthermore, selection of one period over another could favour (or disadvantage) some locations over others in terms of either achieving the specification and/or actual daylighting performance. For example, Spain uses Central European Time and so, given its longitude, solar time is markedly later than clock time for much of the country. This and other locale-specific factors (e.g. typical working period) suggest that a fixed period of the day is not a robust criterion for the purpose of evaluating the *intrinsic* daylighting performance of a space or building.

As noted, the sun altitude condition serves as proxy for daylight hours. The condition sun altitude $\geq 0°$ will *generally* result in the selection of diffuse horizontal illuminance values greater than zero. But that will not always be the case, nor will the condition guarantee the selection of exactly half of the hours of the year (i.e. 4,380) as one might expect. This occurs because the continuous motion of the sun is considered only at fixed intervals (i.e. hourly) resulting in sampling 'edge effects'. The diffuse horizontal illuminance condition serves a similar purpose as sun altitude, though the condition is now applied directly to the data to be sampled rather than via the proxy of sun altitude. Tests revealed that the condition $E_{dh} \geq 0$ lux was especially prone to sampling 'edge effects'. This could be because the protocols for preparing the various climate files from all the disparate sources was not identical, e.g. the criteria used to reset low E_{dh} values to zero were different. Such effects have no bearing whatsoever on, say, a dynamic thermal simulation, but any procedure based on a proportion of the total (i.e. the median) will be sensitive to the distribution of the data. Thus consistency in the methodology is vital.

We propose therefore a method that reliably, and consistently, selects a fixed sample of diffuse horizontal illuminance values from the annual time-series. Thus avoiding any influence on the outcome resulting from 'edge-effects' etc. The hours of daylight for evaluation are determined by rank-ordering (i.e. from highest to lowest) the 8,760 values for diffuse horizontal illuminance and then extracting the first (i.e. the highest) 4,380 hourly values. Note that the retained (i.e. highest) 4,380 values may include some zero values, or that the discarded 4,380 values may include some non-zero values. This is to be expected given the nature of illuminance data in climate files, and does not affect the outcome. The target daylight factors derived from the median of the selected E_{dh} values are shown in the last row of Table 4. Note that they are very similar, but not exactly the same as those for the sun altitude $\geq 0°$ condition. Because, as noted, that sun altitude condition cannot be relied upon to select exactly 4,380 E_{dh} values. The D_T values in the last row vary from 1.77% (for Madrid and Rome) to 2.55% for Ostersund – a range of 0.78%.

3.4 Summary of the 'Proposal'

The proposal, for side-lit spaces with windows on one facade, is as follows:

> **A design should achieve a target daylight factor (D_T) at workplane height across half of the relevant floor area for half of the daylight hours in the year, where D_T is based on the provision of 300 lux.**

Definitions:

- The target daylight factor is derived from the median of the diffuse horizontal illuminance data for daylight hours by applying the daylight factor relation between internal and external diffuse illuminance.
- The daylight hours are defined as the the 4,380 highest values for diffuse horizontal illuminance in the (rank ordered) data.
- The diffuse horizontal illuminance data used is appropriate to the locale of the building/space under evaluation.
- The relevant floor area is the entire regularly occupied floor area for the space less a 0.5m perimeter zone.

Target daylight factors for a 32 EU and capital cities and Moscow are given in the next section.

3.5 Example target daylight factors for 33 capital cities

Target daylight factors for 32 European capital cities and Moscow are shown in Table 5. The the sources of diffuse horizontal illuminance data were the EnergyPlus website and, for cities not in the EnergyPlus database, the SATEL-LIGHT European Database of Daylight and Solar Radiation. In the first instance we would recommend the use of standardised climate files since the data are based on direct measurements. On the basis of limited testing for a handful of locations, we have observed in general good agreement in D_T (actually, diffuse horizontal illuminance values) between the standardised and satellite-derived data. Whilst this is encouraging, it would appear prudent to recommend some further testing of satellite-derived illuminance data against that from standardised climate files. Furthermore, we have noticed one or two standardised climate files that deliver median E_{dh} values a little different from what we might expect. Illuminances are sometimes derived from irradiance values using a luminous efficacy model. We recommend therefore that standardised climate files are also subject to some checking for consistency, etc. We intend to prepare a report in the near future on quality assurance procedures for illuminance data from climate files.

3.6 Latitude dependancy

The BREEAM guide recommends a step-wise latitude dependancy in *average* daylight factor (Table 1). Here we compare the latitude dependancy in target daylight factor (D_T) for the 33 capital cities with the BREEAM scheme. The comparison is plotted in Figure 4. Superficially, there would appear to be reasonable agreement in the general trend. However, the comparison is not like-for-like. As demonstrated in the example shown earlier (Figure 3 and Table 2), the average daylight factor can be markedly different from the median. Also, there is of course noticeable variation in D_T within each of the stepwise bands.

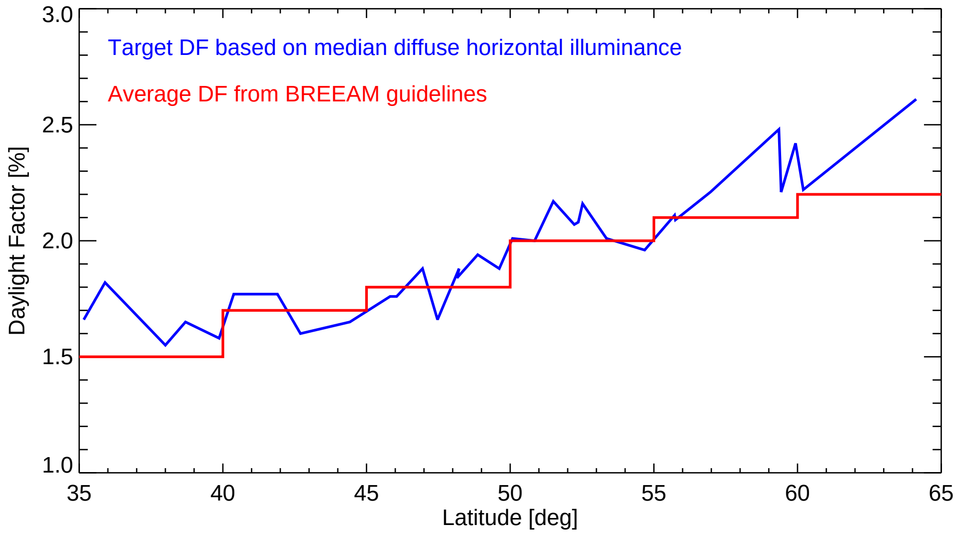

Figure 4: Comparison in latitude dependency

4 SUMMARY

The proposal for a CEN daylighting standard described in this paper offers, we believe, a more robust basis for guidelines than any of the currently used schemes that we are aware of. The basis of the proposal is founded on the availability of daylight and the potential of the space to deliver absolute levels of illuminance over a specified period of the year. The methodology is both simple and clear with, we believe, little potential for accidental or wilful 'game-playing' with regard to the outcome. The 300 lux target illuminance value is supported by a number of studies. The proposal is in fact a refinement of the approach described in the 1970 CIE report "Daylight" [3], and requires only modest enhancement to existing practice. Adoption of the proposal would also facilitate the eventual transition to metrics founded on climate-based daylight modelling. The proposal is not quite complete, since it requires agreement on the target areas for multi-aspect, etc. glazing. These issues however are common to any rating scheme and not particular to the proposal.

This article is the third of a series in support of the activities of CEN TC 169/WG11. The first paper "Rethinking Daylighting and Compliance" was presented at the SLL/CIBSE 2013 International Lighting Conference in Dublin, Ireland [8]. The second paper "A Roadmap for Upgrading National/EU Standards for Daylight in Buildings" was presented at the 2013 CIE Midterm conference in Paris, France [9]. It should be noted that the views expressed in this paper are those of the authors Mardaljevic, Christoffersen and Raynham alone.

Table 5: Median diffuse illuminance and 'target' daylight factor for 33 capital cities

Country	Capital	Median E_{dh} [lux]	Target DF [%]	Latitude [°]
Cyprus	Nicosia	18100	1.66	35.16
Malta	Valletta	16500	1.82	35.90
Greece	Athen	19400	1.55	38.00
Portugal	Lisboa	18220	1.65	38.70
Turkey	Ankara	19000	1.58	39.87
Spain	Madrid	16900	1.77	40.38
Italy	Rome	19200	1.77	41.90
Bulgaria	Sofia	18700	1.60	42.70
Romania	Bucharest	18200	1.65	44.42
Croatia	Zagreb	17000	1.76	45.82
Slovenia	Ljubljana	17000	1.76	46.05
Switzerland	Bern	16000	1.88	46.95
Hungary	Budapest	18100	1.66	47.47
Austria	Wien	16000	1.88	48.22
Slovakia	Bratislava	16300	1.84	48.15
France	Paris	15900	1.94	48.87
Luxembourg	Luxembourg	16000	1.88	49.62
Czech Republic	Prague	14900	2.01	50.08
Belgium	Brussel	15000	2.00	50.85
United Kingdom	London	14100	2.17	51.50
Poland	Warsawa	14700	2.07	52.23
The Netherlands	Amsterdam	14400	2.08	52.37
Germany	Berlin	13900	2.16	52.52
Ireland	Dublin	14900	2.01	53.35
Lithuania	Vilnius	15300	1.96	54.68
Denmark	Copenhagen	14200	2.11	55.72
Russian Fedn.	Moscow	14800	2.09	55.75
Latvia	Riga	13600	2.21	56.97
Sweden	Stockholm	12100	2.48	59.35
Estonia	Tallinn	13600	2.21	59.43
Norway	Oslo	12400	2.42	59.93
Finland	Helsinki	13500	2.22	60.20
Iceland	Reykjavik	11500	2.61	64.13

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