Prescribing for Daylight: Can We Account for the Disparate Measures Within a Unified Modelling Framework?

J. Mardaljevic[1], & M. Andersen[2]

[1] *School of Civil & Building Engineering, Loughborough University, Leicestershire, LE11 3TU,UK*
[2] *EPFL ENAC IA LIPID, Lausanne, CH - 1015, Switzerland*

Introduction

The potential for a building design to provide daylight for general illumination was, until very recently, evaluated using only the daylight factor, i.e. a ratio of internal to external illumination under a single standardised overcast sky. Other known effects of daylight, such as the occurrence of visual discomfort which is more likely to occur during non-overcast conditions, were assessed or estimated by other means, often relying more on the skill of the experienced lighting designer than by use of a repeatable set procedure. In the last few decades there has been a gradual increase in awareness of the non-visual effects of daylight/light received by the eye Webb (2006). The quality and nature of the internal daylit environment is believed to have a significant effect on human health in addition to general well-being and worker productivity.

Demonstrating compliance with various guidelines at the design stage is an ever increasing concern. For daylight this is invariably carried out nowadays using simulation rather than scale models. After many decades of reliance on the daylight factor as the sole quantitative daylight metric, there has been an explosion of activity in daylight modelling research which has delivered numerous new techniques, approaches and metrics. This paper describes various end-user requirements - both current and emerging - for daylight modelling and discusses how these might be accommodated within a single modelling framework.

End-user requirements

End-user requirements will vary greatly depending on their needs. Does the user want to “understand” the spatio-temporal dynamics of illumination in the space, or do they only require some “bottom-line” summary metric? Software designed for the former requirement could most likely be easily modified to deliver summary metrics also. The reverse is unlikely to be true since the tool for the summary metrics was most likely designed to deliver these by the most straightforward procedural means. Thus the framework used is unlikely to be readily extensible in order to accommodate modelling modalities that were not originally envisaged by the tool designer.

Inevitably there is a strong trend in the formulation of compliance guidelines towards seemingly unambiguous summary metrics, often a single “target” value, e.g. the space achieves an average daylight factor of 2%. The rationale for this is twofold. Firstly, the quite reasonable belief that simple targets are likely to be both easy to compute and easy to understand. Secondly, the belief that the more complex the target the greater the chance for “game playing” in demonstrating compliance with it. There is much truth in both of these beliefs, however recent developments have demonstrated that some quite seemingly simple daylight targets are in fact quite challenging to predict. e.g. LEED daylight proposal. Long-standing simple targets such as achieving an average DF of 2% are also open to game playing and mis-interpretation.

Even something as simple as specifying a sensor grid is not as straightforward as might seem at first, depending on the application. For example, a rectangular workplane can be easily converted to a grid of horizontal sensor points. But what if the evaluation also requires simulation of light that arrives at the eye for modelling non-visual effects and/or visual comfort, e.g. vertical illuminance or scene luminance? The eye will be at a vertical height ~40 cm above the workplane, and can, in principle, have any view direction though it will tend to be "across" the workplane. Given that workplanes can be arbitrary in shape, it is unlikely that an automated scheme could reliably locate the occupants' eye sensor point and typical view direction from just a horizontal workplane - manual intervention would most likely be required.

Climate-based metrics

Climate-based daylight modelling (CDBM) is now established as the successor to the standard "snapshot" approaches such as the daylight factor. Climate-based modelling delivers predictions of absolute quantities (e.g. illuminance) that are dependent both on the locale (i.e. geographically-specific climate data is used) and the building orientation (i.e. the illumination effect of the sun and non-overcast sky conditions are included), in addition to the building's composition and configuration. Whilst the various underlying "engines" for CBDM are relatively well-established, having undergone varying degrees of validation, there is little consensus on the form that the metrics derived from predictions should take. For example, having generated an annual time-series for illuminance at, say, the work-plane, the overall provision needs to be assessed using one of the various metrics that have been proposed, e.g. Useful Daylight Illuminance - Mardaljevic and Nabil (2005), Daylight Autonomy - Reinhart et al. (2006), Acceptable Illuminance Extent - Kleindienst and Andersen (2012), amongst others.

Daylight illuminance on a horizontal plane for task is just one aspect of daylight provision. Additional phenomena / effects that we might wish to gain knowledge of at the design stage include:

- The potential to displace electric lighting.
- The propensity for visual discomfort.
- Some measure of the accessibility and the nature of the views to the outside.
- An indication of the potential for daylight to produce non-visual effects (once associated models are better defined).

Thus, there are multiple daylight and daylight-related quantities that each require some measure which, in principle, could be predicted at the design stage for the purpose of evaluation and/or compliance testing. This abstract describes various approaches that have been devised to predict these quantities, giving examples in each case. The final presentation contains a discussion on the potential to integrate these approaches into a unified scheme. Necessarily, the practicalities with respect to the computation of each individual solution will figure in the discussion. The main thrust of the discussion however will be to determine what properties/dimensions of the (for most cases) inherently spatio-temporal nature of the various metrics need to be made available to the designer, and what form the presentation of data should take. For the end-user/client, the various outputs should be perceived as offering a holistic insight into the daylighting performance of the space, rather than as a series of plots with seemingly little relation to each other. Thus our notion of a 'unified framework' applies to both the practicalities of the input and the intelligibility of the output.

Spatial Properties of Daylight Provision

One metric used to evaluate daylighting provision - which correlates somewhat with the potential to displace electric lighting - is the "useful daylight illuminance" (UDI) scheme devised by Mardaljevic and Nabil (2005). Put simply, achieved UDI is defined as the annual occurrence of illuminances across the work plane that are within a range considered "useful" by occupants. Thus UDI is in part a human factors derived metric. The UDI scheme is applied by determining at each calculation point the occurrence of daylight levels where:

- The illuminance is less than 100 lux, i.e. UDI 'fell-short' (or UDI-f).
- The illuminance is greater than 100 lux and less than 300 lux, i.e. UDI supplementary (or UDI-s).

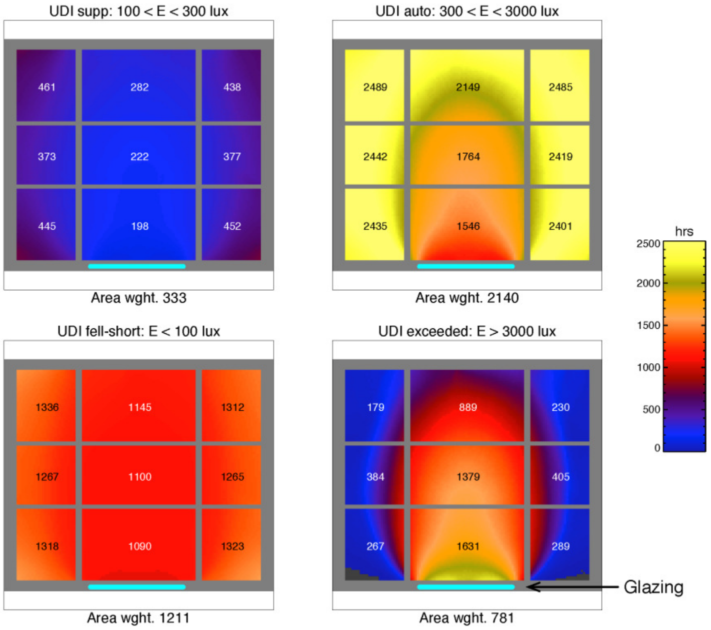

Fig 1: Example UDI

- The illuminance is greater than 300 lux and less than 3,000 lux, i.e. UDI autonomous (or UDI-a).
- The illuminance is greater than 3,000 lux, i.e. UDI exceeded (or UDI-e).

Daylight autonomy, another climate-based metric, is a measure of how often in the year a specified illuminance (e.g. 300 lux) is achieved. The daylight autonomy value for an illuminance of 300 lux is very similar to UDI-a. The main difference is that the UDI scheme includes the occurrence of exceedances of an upper illuminance limit, in this case 3,000 lux. Thus, the annual occurrence of UDI-a will generally be less than that for DA at 300 lux.

With UDI the user may be presented with four plots showing the annual occurrence in each of the UDI categories as a false-colour spatial map, Figure 1. Here the occurrence was determined between the hours 08h00 and 20h00. The space is a residential living room with a window on one side. Within reason, any number of sensor planes could be used to cover the room area – here there are nine. Each of the distinct sensor planes is annotated with the mean value for the occurrence across that plane. Thus the average occurrence of UDI-a (i.e. 300 to 3,000 lux) for the central sensor plane in the middle of the room was 1,764 hours. If a single value is needed to characterise the space for each of the four categories, then an area weighted value for all the sensors is probably the most appropriate. In which case, the daylighting performance of the entire space could, in UDI herms, be characterised for just four numbers. Whilst UDI-e *may* be a proxy for the potential of visual discomfort, it is not yet known how robust or reliable the relation between the two might be.

Temporal Properties of Daylight Provision

To address the issue of data overload resulting from annual analyses, a novel goal-based metric, called Acceptable Illuminance Extent or AIE, reports the per cent of an area of interest that stays within a user-defined illuminance goal range (Kleindienst and Andersen, 2012); in other words, it defines the amount of space that stays within acceptable limits at any given moment in time and thus avoids any kind of Ð potentially misleading - averaging. It is conceptually similar to the UDI metric in that it applies a lower and an upper threshold, but it has fuzzy boundaries and, more importantly, it relates to a whole perimeter of interest.

Starting from illuminance goals driven by the design intent (e.g. derived from norms or regulations), AIE can be calculated as follows: given an array of illuminances over an area of interest (AOI), the number of

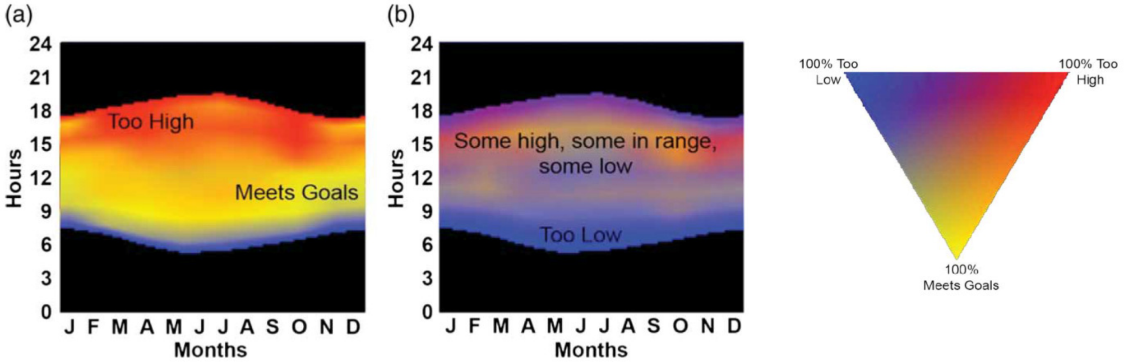

Fig 2: Example AIE

sensor points (or sensor patches in the case of radiosity-based calculations) that fall within the desired range is determined, as well as the number of sensors where illuminances were too high or too low. The per cent of total sensors that fall within the goal range is the AIE, illustrated in Figure 2.

To display this information in an intuitive and efficient way, the temporal map format is used that shows how much of any given area of interest falls within the desired range at any given moment in time, as illustrated in Figure 2. The colour scale was introduced in Kleindienst and Andersen (2012) to communicate information about goals exceedance, falling short and compliance in a single graph. The scale is triangular (Figure 2) where yellow represents data that have met the designer's goals, blue represents data that are too low, and red represents data that are too high. Following from this, purple, for example, represents a moment when the data include both high and low values, such as in a dim room with direct sun spots. Any colour within the triangle is thus a possible outcome.

Potential for non-visual effects

The daily cycle of day and night plays a major role in regulating and maintaining 24-hour rhythms in many aspects of our physiology, metabolism and behaviour. The retina of the eye contains not only the well-known photoreceptors which are used to detect light for vision (i.e. rod and cones) but also contain a subset of specialised retinal ganglion cells that are intrinsically photosensitive and project directly to brain areas mediating 'non-visual' responses to light. The timing, intensity, spectrum, duration, pattern of light received at the eye, and prior light history, are the principal factors determining entrainment of the circadian cycle. An attempt at combining intensity of light exposure at the eye with timing (and to some extent spectrum) into a condensed format has been proposed in the form of a 'sombrero' plot, reproduced in Figure 3, which "categorises" circadian entrainment in three periods of the day (represented as three concentric rings) based on their expected effects on our biological

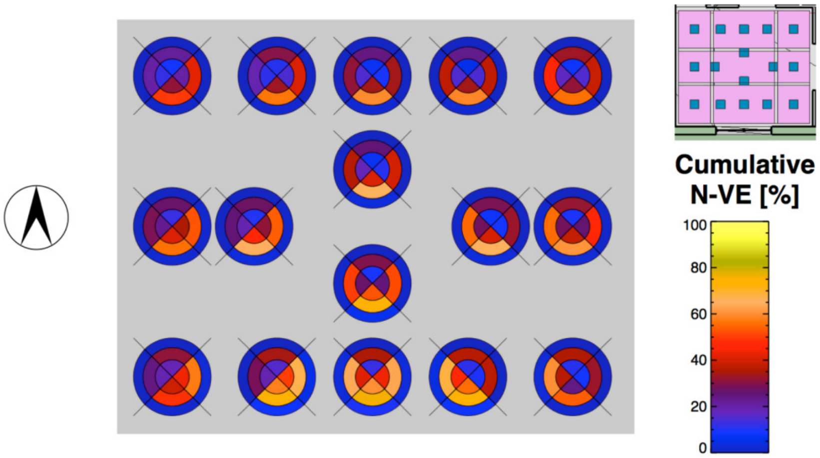

Fig 3: The 'sombrero' plot

clock (Andersen et al., 2012). It thus offers a particularly synthetic visualisation of ‘potential for non-visual effects’ for a given location, and for four view directions. Its combination with a temporal map information can bring very valuable and intuitive input for design decisions, by quickly pointing out at potential light over- or under-exposure depending on the time of day. For example, high values for late evening exposure (outer ring) should typically be avoided for a healthy dark-light cycles. The space used for this example was the same as that in Figure 1. However, the 16 potential occupant head positions were manually located rather than derived directly from the 9 workplanes.

Discussion

Is it possible to carry out these and other disparate evaluations within a ‘unified modeling framework’? To be discussed in the full presentation.

Acknowledgements

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References

Andersen, M., Mardaljevic, J., and Lockley, S. 2012. A framework for predicting the non-visual effects of daylight – Part I: photobiology-based model. *Lighting Research and Technology*, 44(1):37–53.

Kleindienst, S. and Andersen, M. 2012. Comprehensive annual daylight design through a goal-based approach. *Building Research & Information*, 40(2):154–173.

Mardaljevic, J. and Nabil, A. 2005. The useful daylight illuminance paradigm: A replacement for daylight factors. *Lux Europa, Berlin*, pages 169–174.

Reinhart, C. F., Mardaljevic, J., and Rogers, Z. 2006. Dynamic daylight performance metrics for sustainable building design. *Leukos*, 3(1):7–31.

Webb, A. R. 2006. Considerations for lighting in the built environment: Non-visual effects of light. *Energy and Buildings*, 38(7):721–727.

Wienold, J. and Christoffersen, J. 2006. Evaluation methods and development of a new glare prediction model for daylight environments with the use of ccd cameras. *Energy and Buildings*, 38(7):743–757.