DAYLIGHTING METRICS: IS THERE A RELATION BETWEEN USEFUL DAYLIGHT ILLUMINANCE AND DAYLIGHT GLARE PROBABILITY?

J. Mardaljevic[1], M. Andersen[2], N. Roy[3] and J. Christoffersen[3]
[1]IESD, De Montfort University, The Gateway, Leicester, LE1 9BH, UK
[2]EPFL ENAC IA LIPID, Lausanne, CH - 1015, Switzerland
[3]VELUX A/S, Ådalsvej 99, DK-2970, Hørsholm, Denmark
contact e-mail: jm@dmu.ac.uk

ABSTRACT

The establishment of climate-based daylight modelling within research and practice has led to a fundamental reassessment of both the basis and purpose of daylight metrics. Whilst there is no consensus yet on the precise nature of the metric(s) that should replace the daylight factor, it is generally agreed that these should be founded on climate-based daylight modelling (CBDM).

In this paper we examine the relation between the predicted annual occurrence of glare and one of the candidate CBDM metrics that has been proposed, called useful daylight illuminance (UDI). The purpose is to determine if one or more of the UDI metrics (predicted for the horizontal workplane) could serve as a proxy for the probability of daylight glare (i.e. a measure of vertical illuminance received at the eye). For glare we use the simplified daylight glare probability model. The setting is a residential building which we use as a 'virtual laboratory' in two design configurations, each evaluated under all 32 combinations of 8 European climates and 4 building orientations.

INTRODUCTION

Climate-based daylight modelling generates a time-series of predictions per point evaluated, usually hourly (or more frequent) for a full year. Furthermore, because realistic sun and sky conditions are employed in the simulation, the output will contain the extremes in the luminous environment that are typically encountered in actual buildings under real skies. The basis of the standard daylight factor method cannot be extended to account for real sky conditions with sun [Mardaljevic et al., 2009]. The output from climate-based daylight modelling - a time-series of illuminance and/or luminance values - needs to be assessed in terms of both the frequency of occurrence and the magnitude of the quantity under consideration. Whilst these are relatively straightforward measures to derive from simulated data, e.g. the number of hours in the year for which the horizontal illuminance was between 300 and 3,000 lux, there is no consensus yet as to what should be the target values for these measures. Furthermore, there is little if any notion what the relation might be between say, a (climate-based) metric for illuminance at the work plane and a metric for daylight glare based on predictions at the eye position. Thus, investigations at this stage are, necessarily, exploratory in nature.

In this study we use a space in a residential building as a 'virtual laboratory' to investigate the relation between the useful daylight illuminance (UDI) metric calculated at the work-plane and the simplified daylight glare probability (DGPs) metric calculated at the eye point [Wienold, 2009]. The study is not intended to be particular to a residential building – the purpose of the space used is simply to offer a wide range of daylight exposures depending on position in the room, direction of view, orientation of the building, building location (i.e. prevailing climate) and, lastly, glazing configuration (the space was evaluated with and without skylights). The investigation reported here is an extension to a much wider study into daylight metrics for buildings [Mardaljevic et al., 2011].

SCENARIO AND SIMULATION

The setting for the study and various parameters explored are described in this section together with an overview of the simulation engine.

Building model and sensor planes

The 3D model for the residential building is shown in Figure 1. The space used for this study was the living room – identified by a dashed ring in Figure 1. The living room has a glazed double door, which is the only vertical glazing. For occupants seated close to the doors, the aspect will be not too dissimilar to that offered by a non-domestic building with floor to ceiling glazing. The wider evaluation determined the effect on various metrics resulting from the addition of skylights (Figure 1). The coloured areas in the plan view show the 'sensor' planes where horizontal illuminance was predicted. For the living room, there are nine sensor planes at table height (coloured pink ■) that were used to assess general daylighting provision in terms of useful daylighting illuminance. The sixteen smaller (0.3m square) sensor planes (coloured blue ■) were first located at head height, and used to predict vertical illuminance at the eye in the four cardinal directions.

The aim of the study reported here is to determine if there is the potential to employ UDI as a proxy for DGPs. Thus it was decided to use sensor planes for

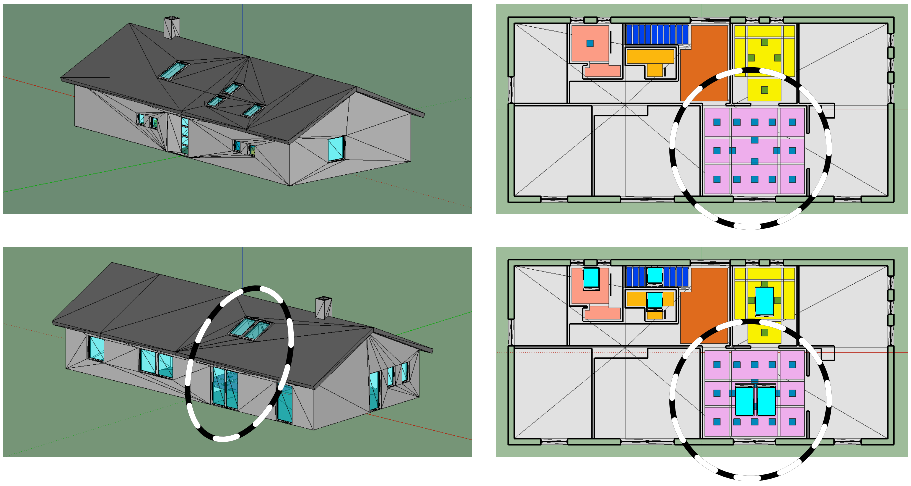

Figure 1: Images of the two main building facades (variant with skylights) together with a plan view showing the calculation planes for the spaces and the smaller, square planes for the DGPs evaluation.

UDI that were the same size as those used for DGPs, but now at table height, Figure 2. This was to avoid the use of, essentially, arbitrary-sized sensor plane combinations when determining the relation between UDI and DGPs. Additionally, if the potential does exist, then it opens up the possibility of re-using the work-plane height sensor grid at eye-height, which could greatly simplify any combined spatial evaluation of both daylight provision and glare propensity.

Number of cases

The living room space had 16 locations where a head might be positioned. For each of these there were four possible view directions, i.e. the 'cardinal' directions at increments of 90°. The building models were evaluated under 8 European climates (see Table 1) and for each of 4 building orientations. There were 2 building models, i.e. without and with skylights. Thus there were a total of $16 \times 4 \times 8 \times 4 \times 2 = 4069$ unique combinations of the above. A time-series of the vertical illuminance at the eye was generated for each of the 4,069 unique cases. These were generated at a time-step of 15 minutes for all daylight hours in a 365 day year.

Table 1: The eight climate files used in the study

ID	Lat	Long
DEU-Hamburg	53.63	-10.00
ESP-Madrid	40.41	3.68
FRA-Paris	48.73	-2.4
GBR-London	51.15	0.18
ITA-Roma	41.80	-12.50
POL-Warsaw	52.17	-20.97
RUS-Moscow	55.75	-37.63
SWE-Ostersund	63.18	-14.50

Climate-based daylight modelling

Climate-based daylight modelling is the prediction of luminous quantities (i.e. illuminance and/or luminance) using realistic sun and sky conditions that are derived from data in standardised climate files. A climate-based analysis is intended to capture all of the unique sun and sky conditions over a period of time rather than be simply a "snapshot" of specific conditions at a particular instant. Because of the seasonal variation of daylight, the evaluation period is normally taken to be an entire year. The basic daylight coefficient (DC) scheme described by Tregenza and Waters was implemented into the *Radiance* lighting simulation system and the predicted illuminances tested against the BRE-IDMP validation dataset [Mardaljevic, 2001]. Tregenza and Waters proposed that the sky be divided into 145 patches and these be used to determine the contribution from both the sun and the sky. However, when tested, this 'basic' DC scheme produced large errors whenever there was a significant divergence between the actually occurring sun position and the nearest pre-computed DC patch value. The basic DC scheme was improved and a refined formulation was devised which gave accuracies comparable the best that could achieved using the standard *Radiance* calculation method, i.e. typically within $\pm 10\%$ of measurements from the BRE-IDMP validation dataset [Mardaljevic, 2000].

The refined DC method computes separate coefficients for the direct and diffuse components from the 145 patches on the hemisphere. The 145 patch scheme is used to compute direct sky illuminance E^d_{sky}, indirect sky illuminance E^i_{sky} and indirect sun illuminance E^i_{sun}. The direct sun component E^d_{sun} however is determined from a finely discretised set of $\sim$5000 patches on the hemisphere. This ensures that the spatio-temporal dynamics of direct sun exposure are precisely determined. This also allows a time-step shorter than one hour to be used without loss of precision. The total illuminance E is the sum of the individual components:

$$E = E^d_{sky} + E^i_{sky} + E^d_{sun} + E^i_{sun} \tag{1}$$

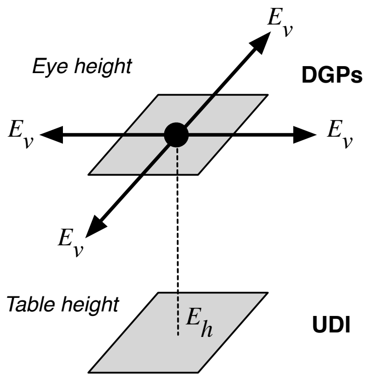

Figure 2: UDI calculation planes were the same size and directly below the planes used to predict vertical illuminance at the eye

This formulation turned out to be fortuitous for the study described here since it allowed for the separation of the sun and sky components of illumination which was required for both the modelling of non-visual effects and glare. Interpolation of the climate data to a 15 minute time-step was found to be sufficient to finely resolve the progression of the sun thereby reducing sampling errors to a minimum. Internal daylight illuminances therefore were predicted at 15 minute intervals. The sky model mixing function described by Mardaljevic [2005] was used to determine the varying sky luminance patterns at each time-step.

DAYLIGHT METRICS

A metric is some mathematical combination of (potentially disparate) measurements and/or dimensions and/or conditions represented on a continuous scale [Mardaljevic et al., 2009]. The full study investigated various metrics for daylighting and daylight-related quantities: general daylight provision with UDI; electric lighting usage; and, a framework for predicting the non-visual effects of daylight that could ultimately serve as the basis of a metric. The study was then extended to investigate the work reported here: the relation between UDI and DGPs.

Useful daylight illuminance: A human factors-based metric

The metric used to evaluate the daylighting provision was 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. The range considered useful is based on a survey of reports of occupant preferences and behaviour in daylit offices with user operated shading devices. For example, a field study conducted by the Institute for Research Construction (Canada) recorded that illuminances larger than, or equal to, 150 lux were classified as 'appreciable daylight' [Reinhart, 2002]. A survey of the work spaces of a computer company showed that most employees felt comfortable with a lighting level of around 100 lux (as opposed to the standard regulations of workplaces demanding 300 lux to 500 lux at desk level) [Schuler, 1995]. It has also been observed that people tend to tolerate much lower illuminance levels of daylight than artificial light, particularly in diminishing daylight conditions at the end of the day, such as continuing to read at daylight levels as low as 50 lux [Baker, 2000]. In a study carried out by the Lawrence Berkeley National Laboratory (USA), office workers were allowed to create their own lighting environment by manually controlling blade angles of mechanical Venetian blinds and varying the intensity of electric lighting. The illuminances recorded during the study were in the range 782 lux to 2146 lux [Vine et al., 1998]. In a UK study it was noted that the daylight illuminance range of 700 lux to 1800 lux appeared to be acceptable for both computer and paper-oriented tasks [Roche, 2002].

Thus, based on the above and other published sources, daylight illuminances in the range 100 to 300 lux are considered to be effective either as the sole source of illumination or in conjunction with artificial lighting. Furthermore, daylight illuminances in the range 300 to around 3,000 lux are often perceived either as desirable or at least tolerable. Note that these values are based on surveys carried out in non-residential, largely office buildings where daylight-originated glare on visual display devices is a common problem. Many of these surveys were carried out before LCD display panels - which are much less prone to glare than CRT screens - became commonplace. It should be noted that there is considerable uncertainty regarding preferred/tolerated upper limits for both non-domestic and residential buildings, and that the UDI ranges should be taken as illustrative and subject to later revision rather than fixed in perpetuity.

UDI achieved is therefore defined as the annual occurrence of daylight illuminances that are between 100 and 3,000 lux. The UDI range is further subdivided into two ranges called UDI-supplementary and UDI-autonomous. UDI-supplementary gives the occurrence of daylight illuminances in the range 100 to 300 lux. For these levels of illuminance, additional artificial lighting *may* be needed to supplement the daylight for common tasks such as reading. UDI-autonomous gives the occurrence of daylight illuminances in the range 300 to 3000 lux where additional artificial lighting will most likely not be needed. 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).
- 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 100 lux and less than 3,000 lux, i.e. UDI combined (or UDI-c).
- The illuminance is greater than 3,000 lux, i.e. UDI exceeded (or UDI-e).

As noted, the UDI ranges were based on a distillation of values from surveys carried out in office spaces, and many of them before LCD screens became commonplace. Also, the recent findings regarding the role of illumination in maintaining the circadian rhythm suggest that regular exposure to high illuminances during daytime could have long-term beneficial health effects [Webb, 2006].

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:

$$DA_{300} = UDI_a + UDI_e \qquad (2)$$

There is a discussion of daylight metrics for illuminance on the task area (e.g. work plane) in Reinhart et al. [2006]. An example set of UDI plots for one of the 64 combinations of climate, building orientation and glazing configuration are shown in Figure 3. Note that this shows the distribution in UDI across the nine sensor planes defined for the room in general rather than the sixteen, smaller planes used for the comparison with DGPs (Figure 1). At the time of writing, there are no commonly agreed 'target' values for any climate-based daylight metric, e.g. UDI or DA – though various proposals are under consideration for LEED in the US. Notwithstanding that lacuna, climate-based metrics have been successfully used in daylighting evaluation, and can be particularly effective when different design options are being compared. For example, with UDI the aim would be to maximise the occurrence of illuminances in the 300 to 3,000 lux UDI-a range, whilst not allowing undue occurrence of illuminances >3,000 lux in the UDI-e range. This 'design goal' for UDI-a and UDI-e is used here as the basis for an evaluation of the relation of UDI with DGPs.

Daylight and glare

In the CIBSE Lighting Guide LG7 glare is defined as a "Condition of vision in which there is discomfort or a reduction in the ability to see details or objects, caused by an unsuitable distribution or range of luminance, or to extreme contrasts" [LG7 CIBSE/SLL, 2005]. There are two types of glare: disability glare, where stray light reaching the eye results in a reduction of visibility and visual performance, and discomfort glare, which leads to users' discomfort, often with less immediately noticeable effects such as headaches or posture related aches after work. Glare can be caused by direct sunlight through a window or by the luminance differences between bright areas such as windows with bright sky views and the darker task area. Furthermore, veiling reflections on reflective surfaces such as computer screens can affect visual comfort at workstations facing away from the window.

While there are accepted, albeit imperfect, models for the potential glare effect of (fixed output) luminaires, it is recognised that glare from daylight sources is relatively poorly understood [Osterhaus, 2005]. The first daylight glare formulations were extrapolations from studies of discomfort glare due to artificial lighting [Chauvel et al., 1982]. The light sources used in those studies subtended relatively small solid angles from the viewpoint of the subject, and the luminance conditions (source and environment) were very different from typical daylit spaces. A review in 2005 by the chair of the International Commission on Illumination (CIE) Technical Committee on glare, concluded that the "available assessment and prediction methods are of limited practical use in daylit situations" [Osterhaus, 2005].

It was with the emergence of high dynamic range (HDR) imaging that significant advances in the formulation of glare metrics were made. With HDR imaging it is possible, using a fish-eye lens, to record the luminance field over an entire hemisphere, i.e. every pixel in the image is a measure of luminance at that point in the scene [Painter et al., 2009]. This allowed for the design of experiments that related subjective user response to objective measurements of the entire luminance field as experienced by the user. The new glare metric that resulted from the experiments carried out by Wienold and Christoffersen [2006] is called daylight glare probability (DGP). The formulation for that metric, and the simplified variant of it used in this study are described below.

Simplified daylight glare probability

The basic form of the equation derived by Wienold and Christoffersen [2006] for daylight glare probability (DGP) was:

$$DGP = c_1 E_v + c_2 \log\left(1 + \sum_i \frac{L_{s,i}^2 \omega_{s,i}}{E_v^{c_4} P_i^2}\right) + c_3 \qquad (3)$$

where E_v is the vertical illuminance at the eye [lux], L_s is the luminance of the source [cd/m^2], ω_s is the solid angle of the source [sr], and P is the Guth position index. Thousands of different parameter combinations were tested using a random optimisation algorithm. The highest correlation with subjective glare rating was found for the following combination of parameter settings:

$$c_1 = 5.87 \cdot 10^{-5} \quad ; \quad c_2 = 9.18 \cdot 10^{-2}$$
$$c_3 = 0.16 \quad ; \quad c_4 = 1.87$$

The DGP is determined for all sources i in the captured (or simulated) HDR image. For a climate-based

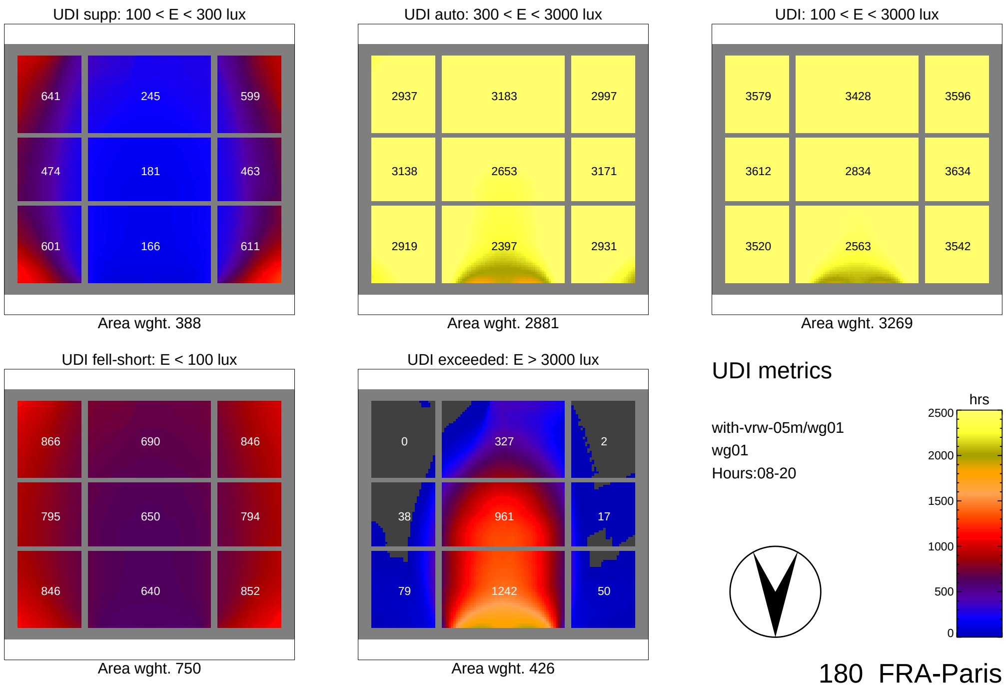

Figure 3: Example UDI plots

daylight simulation, the evaluation of DGP would require the generation of a suitable hemispherical fish-eye image at each time-step of the annual simulation, e.g. up to 4,380 images (per view point and per view direction) for a time-step of 1 hour. This presents a considerable computational overhead, both for the generation of the images and the post-processing of the data to detect and sum all the luminance sources. For certain conditions, which greatly simplified the computational task, there was a high correlation between vertical illuminance at the eye and DGP. This finding was, it seems, quite unexpected since the (eliminated) contrast term was thought to be a significant factor even in the 'no sun' cases. This discovery led to the formulation of simplified daylight glare probability, referred to as DGPs [Wienold, 2007]. The condition that needs to be observed is that no direct sun – or specular reflection from it – arrives directly at the eye. The middle term in equation 3 is eliminated and the c_1 and c_3 parameters take on the values $6.22 \cdot 10^{-5}$ and 0.184 respectively. The equation for simplified DGP is therefore:

$$DGPs = \left(6.22 \cdot 10^{-5} \cdot E_v\right) + 0.184 \qquad (4)$$

Referred to as DGPs, the value was determined from the time-series of illuminances predicted at the eye (E_v) for each of the 4,096 individual cases described earlier – and excluding those instances where direct sun reaches the eye. The removal of those instances where direct sun enters the eye is of course a simplification, but perhaps not as great as first imagined. Unless the solar disc is effectively totally obscured it will nearly always result in a glare/discomfort sensation when directly visible to the eye. The consideration of direct sun via specular reflection was important in the original case study because "shiny" Venetian blinds were deployed by the occupants to moderate sun. So the reflection of 'direct' sunlight from these was a potential source of visual discomfort. And therefore such reflections are accounted for in simulations of spaces that have Venetian or similar blinds. The residential space did not have Venetian blinds, and no shading device of any type was modelled. In a residential setting, the exclusion of instances where direct sun enters the eye is comparable to the drawing of curtains or (fabric) shades - which, one assumes, would result in a 'no discomfort' condition.

Daylight glare comfort classes

An attempt to formulate glare metrics for annual (i.e. climate-based) simulations was made by [Wienold, 2009] using an analogue of a method to assess thermal comfort. Based on an analysis of the data collected in their field study, a set of 'comfort classes' named A, B and C were derived:

- A – best class, 95% of office-time glare weaker than 'imperceptible'.
- B – good class 95% of office-time glare weaker than 'perceptible'.
- C – reasonable class 95% of office-time glare weaker than 'disturbing'.

The recommendation given is that the 95% of the occurrences of DGPs should be below a certain value to qualify for the class. And further that the mean of the remaining 5% of occurrences should also be below an upper limit to qualify for the class. The limits of DGPs for the 95th percentile ($L^{95\%}_{DGPs}$) and the mean for the remaining 5 percent of the time ($M^{5\%}_{DGPs}$) are given below in Table 2. This seems a promising approach, but until further studies support these ranges they should be considered provisional.

Table 2: DGPs limits

Class	A	B	C
95% DGPs limit	≤ 0.35	≤ 0.40	≤ 0.45
Mean DGPs (5%)	< 0.38	< 0.42	< 0.53

RELATION BETWEEN UDI AND DGPs

Our intention here is to investigate the relation between UDI and DGPs rather than attempting to summarise it using some measure or statistic. Because, as noted, we do not yet have agreed 'targets' for the occurrence of any of the UDI metrics. Furthermore, DGPs (and DGP) are also new metrics where the suggested targets for occurrence should, as noted, be seen as advisory/provisional. Thus, an essentially arbitrary selection of target criteria for UDI and DGPs would lead to a result that was at risk of also seeming to be arbitrary. That being so, our primary aim is to investigate the data *visually* to determine if scatter and density plots reveal distinct populations distributions in the occurrence of $L^{95\%}_{DGPs}$ for instances when the horizontal illuminance is in: (a) the UDI-a range; and, (b) the UDI-e range. The presence of distinct populations would support further development of the approach. Each of the 4,096 annual time-series for vertical illuminance received at the eye were processed as follows:

- The annual time-series of vertical illuminance was converted to $DGPs$ using equation 4.
- Instances where the direct sun component of vertical illuminance was greater than zero were removed from the time-series.
- Illuminances that occurred outside of the period of evaluation 09h00 to 17h00 were removed from the time-series.
- For the values remaining in the $DGPs$ time-series, the 95th percentile value for simplified daylight glare probability ($L^{95\%}_{DGPs}$) and the mean for the remaining 5 percent ($M^{5\%}_{DGPs}$) were determined.

The data were examined as both scatter and density plots. The first pair of plots shows the relation between $M^{5\%}_{DGPs}$ and $L^{95\%}_{DGPs}$, Figure 4. Here it is apparent that the majority of the 4,096 cases fall into the 'best' class (A), i.e. both conditions $L^{95\%}_{DGPs} \leq 0.35$ and $M^{5\%}_{DGPs} < 0.38$ are fulfilled. Of the 4,096 cases, 2,917 (71%), 3,379 (82%) and 3,715 (91%) fall into the classes A, B and C, respectively (Table 2).

Next, we proceed to relate the number of hours for the occurrence of two key daylight metrics (i.e. UDI-a and UDI-e) with $L^{95\%}_{DGPs}$. These are shown in Figure 5. Due to space limitations the scatter plots are omitted and only the density plots for the UDI relations are shown. Taking first the plot for UDI-a (i.e. the occurrences of illuminances in the range 300 to 3,000 lux) – in the main, these occurred for between ∼1,000 and ∼3,000 hours depending on position in the space, view direction, building orientation, prevailing climate and glazing configuration. Furthermore, these were generally associated with $L^{95\%}_{DGPs}$ values less than 0.35. There were moderate occurrences in the range 0.35 to 0.40, and relatively few with $L^{95\%}_{DGPs} > 0.40$. The companion plot showing the relation for the occurrence of UDI-e to $L^{95\%}_{DGPs}$ is clearly different. Here the density plot reveals a population of points that generally have a low occurrence of UDI-e (as might be expected), but a significant number of these are associated with $L^{95\%}_{DGPs}$ values greater than 0.35 (Figure 5). The false-colour shading scheme was over-ridden to better resolve the 'peak' in each case. The density cells containing the lowest values (i.e. mostly blue) which comprise 25% of the overall total are shaded dark grey, and then those comprising the lowest 10% are shaded black (i.e. some grey are set to black). The black and the grey cells delineate the 'foothills' of the peaked distribution in each case. Thus the remaining coloured cells comprise in each case 75% of the total number of points – green ellipses mark the peak in each case. It evident that, whilst there is a small amount of overlap, the populations in the two density plots are quite distinct.

The next stage

The preliminary results shown here offer sufficient encouragement to pursue further the potential for UDI metrics – or a refinement of UDI – to serve as a proxy for measures of daylight glare probability. The next stage in refining the approach will be to include the use of solid angle information from hemispherical 'fish-eye' views generated for the various possible view positions/directions, Figure 6. The daylight coefficient implementation used for this study calculated illuminance as the sum of four separate components (equation 1). Knowing the illuminance that results from a direct view of the sky (E^d_{sky}), it is then a straightforward matter to calculate the mean sky luminance $\overline{L_{sky}}$ using the relation $E = \pi L$ since, in a hemispherical image, it is proportional to the area of the sky in the image, i.e. number of pixels n_{sky}. Thus the relation between illuminance and luminance becomes:

$$E^d_{sky} = \pi \frac{n_{sky} \cdot \overline{L_{sky}}}{(n_{env} + n_{sky})} \qquad (5)$$

Similarly, the mean luminance of the remainder of the environment $\overline{L_{env}}$ can be determined using:

$$E = \pi \frac{(n_{env} \cdot \overline{L_{env}} + n_{sky} \cdot \overline{L_{sky}})}{n_{env} + n_{sky}} \qquad (6)$$

where n_{env} is the number of pixels comprising the remainder of the hemispherical image, i.e. shown

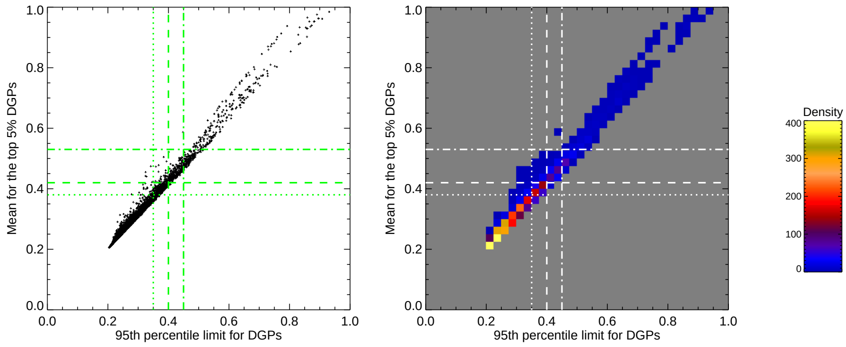

Figure 4: Scatter and density plot for $M^{5\%}_{DGPs}$ versus $L^{95\%}_{DGPs}$

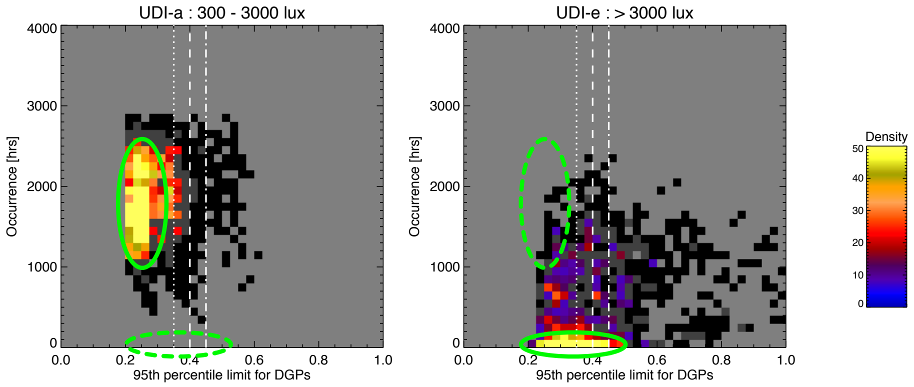

Figure 5: Density plots showing the hours occurrence of UDI-a and UDI-e versus $L^{95\%}_{DGPs}$

Figure 6: Hemispherical fisheye view from one of the locations inside the space

grey/black in Figure 6. A single, computationally cheap, image would required for each potential view position and direction. So both the simulation and post-processing overheads would be negligible. This approach would be similar in principle to the 'enhanced simplified' DGP described by Wienold [2009].

CONCLUSION

This study has demonstrated that there is the potential to compute measures of daylight glare probability using indirect means, i.e. using the simplified DGP and without recourse to generating – computationally expensive – luminance renderings on a per time-step basis. The relation between $L^{95\%}_{DGPs}$ and the two UDI metrics seems sufficiently robust to warrant further development of this approach. The evaluation described here is essentially 'proof of concept', and the next stage of the analysis requires a thorough sensitivity/parametric study to determine the domain of applicability of UDI metrics as a proxy for daylight glare probability. Given the inherent limitations of DGPs, future development will test an enhanced version that makes use of scene luminance information derived from the illuminance components. The validation of the enhanced method will be by testing predictions against the standard, computationally expensive DGP approach for a wider range of architectural types.

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