Evaluation of daylight in buildings in the future

ELPIDA VANGELOGLOU
Ramboll
United Kingdom
e.vangeloglou@gmail.com

HELLE FOLDBJERG RASMUSSEN
MicroShade A/S
hfr@microshade.dk

Building regulation requirements and traditional engineering practice for daylight calculations is often outdated and unsynchronized with the advance and needs of modern sustainable building design. State-of-the-art calculation tools provide accurate results on daylight conditions using methods as simple as calculating the useful daylight illuminance. These methods facilitate sustainable building design that also works in practice. This is illustrated with an example where the daylight conditions in an office with solar shading is examined.

The inevitable turn of the building sector to sustainable design techniques has brought daylight analysis to the center of attention. Buildings with an enhanced daylight performance have minimized energy requirements and an improved indoor climate. However, assessing daylight conditions is somewhat adhered to old-fashioned methods, as building regulations and schemes in most countries are not updated to research findings.

Legislation and standards

Daylight Factor is the most widely used method of establishing compliance with building codes and credits within environmental assessment schemes such as BREEAM, DGNB etc. Taking as example the Danish Building Regulation of 2015 the requirement to achieve sufficient daylight conditions in an occupied space is a minimum of 2% daylight factor (DF) covering part of the work plane. This is a typical requirement from Denmark to United Arab Emirates, although the latter almost never experience a standard CIE overcast sky.

Why is the daylight factor method old-fashioned?

As much as the daylight factor method is easy to comprehend and apply, it leaves the designer a lot of space to produce a building with uncomfortable or energy inten-

Daylight factor (DF)

DF is defined as:

$$DF = \frac{E_{inside}}{E_{outside}} \cdot 100\%$$

where E stands for illuminance.

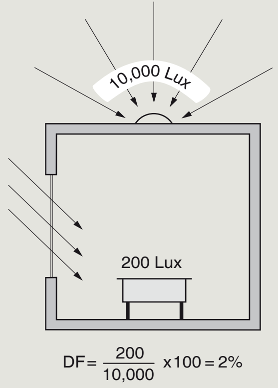


Illustration from By og Byg Anvisning 203 Calculation of daylight in buildings. (2002)

DF is the ratio of the illuminance due to daylight on a surface in a room to the illuminance on an external horizontal surface due to an unobstructed hemisphere of a standard CIE overcast sky. The latter means that direct sunlight to both illuminances is excluded and that orientation and latitude do not affect the value.

sive daylight conditions. That is because DF takes no account of the building location, façade orientation or varying sky conditions. Moreover it provides no indication of glare or visual comfort nor is the solar shading taken into account. The latter is of increasing importance in low energy buildings since the solar shading is more often used and is vital for the expected performance of the building. Several examples show a usage of the solar shading for up to 80% of working hours during the summer in order to maintain a satisfying indoor climate. However, the daylight factor method only evaluates the overcast sky conditions and hence only represents down to 20% of the working hours.

New method - Climate-based daylight metrics

Instead, there are by now several studies1, 2, 3 discussing this exact topic and proving that the introduction of climate-based daylight calculations that rely on hourly meteorological data over the year, form much more accurate and informative, yet simple measures of the daylight conditions in a building compared to the DF and could effectively replace the latter in regulation and scheme requirements.

The *climate-based approach* uses time varying sky and sun conditions, whilst predicting hourly levels of daylight illuminance. This is fully parallel to standard practice for indoor climate simulation. The superiority of the method is thus evident against the daylight factor approach, which is a single number taking no account of orientation and considering only overcast skies, therefore not being meaningful for climates with predominant sun conditions. Moreover the climate-based approach can take solar shading into account.

Indicative calculation metrics of the climate-based method are e.g. the *Daylight Autonomy (DA)* and the *Useful Daylight Illuminance (UDI).*

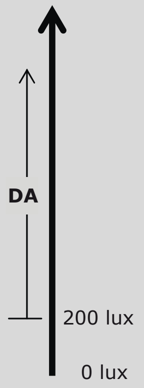
So far the DA and UDI methods are applied by the UK Education Funding Agency for the evaluation of designs submitted for the Priority Schools Building Programme (PSBP)4. Furthermore a variation of DA, the so-called Spatial Daylight Autonomy (sDA) is used in the environmental ration system LEED v45.

Daylight Autonomy

Daylight DA provides the benefit of valuing the contribution of daylight to energy savings; however it is of no value to the occupants' comfort as it does not reflect on the amount of time of extreme illuminance levels causing discomfort or glare. At the same time, the metric ignores illuminances that are below the threshold, which can still be useful to the building users.

Daylight Autonomy (DA)

Daylight Autonomy is defined as the percentage of the working year when a minimum threshold of illuminance can be provided to the work plane by daylight alone – often 200 lux. Thus it is an index directly related to the potential of artificial lighting energy savings.

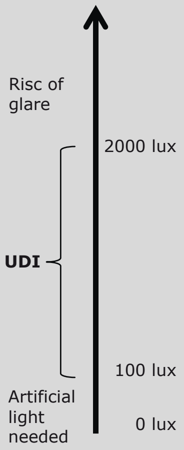


Useful Daylight Illuminance

Useful Daylight Illuminance is more advantageous, because it covers the gaps of DA. The upper and lower threshold of UDI have been defined based on the findings of numerous field studies and surveys in offices[1] indicating that illuminance levels between 100 lux and 2 000 lux are either desirable or tolerable to workers. Hence, UDI informs on how often daylight illuminance is too low, i.e. how often artificial light is needed, how often illuminance is useful to the occupants and how often it is extreme and therefore causes discomfort. Overall, it relies on a detailed method and it gives value to unconventionally useful illuminance levels plus indicating disturbances, whilst giving an impression on the potential for reduced lighting use.

Useful Daylight Illuminance (UDI)

UDI is defined as the percentage of the working year when daylight illuminances on the work plane fall within a certain range – typically 100-2000 lux. Below 100 lux artificial light is needed and above 2000 lux discomfort will occur. Thus UDI stands out as likely the most informative and realistic daylight metric using climate-based data.



How to calculate these metrics?

The daylight factor can be calculated for each evaluation point in the working plane using software that conducts illuminance calculations. These can be simple software packages like Velux Daylight Visualizer or more advanced like Radiance or Daysim.

The calculation of climate-based daylight metrics like UDI requires the use of Climate Based Daylight Modelling (CBDM) programs, e.g. Radiance or Daysim.

Daysim runs annual simulations with detailed climate files by calculating daylight coefficients6. Its simulations give outputs of annual indoor illuminance and luminance profiles. These outputs are combined with a user behavior model and defined illuminance targets, shading controls and lighting controls to predict daylight performance metrics, such as daylight autonomy, useful daylight illuminance as well as artificial lighting energy demand. Daysim uses plug-ins in 3D design tools like SketchUp or Ecotect to import the building's geometry for more accurate simulations. Due to its high accuracy the program requires more simulation time with increasing geometrical details and size of the building model.

A case study with solar shadings

The daylight factor, Daylight Autonomy and Useful Daylight Illuminance was calculated using Daysim for part of an open plan office in Copenhagen oriented south (**Figure 1**).

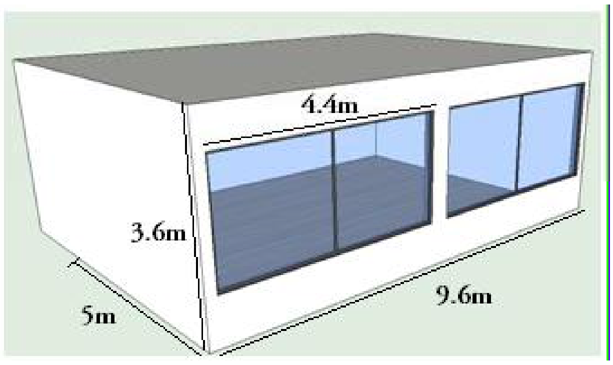


Figure 1. Office in Copenhagen facing south.

The only parameter varying was the solar shading. Five calculations were carried out; a 3-layer low energy glazing without solar shading for reference, a low energy glazing with an external dynamic venetian blind, a solar control glazing (like Pilkington Suncool 40/22), a MicroShade glazing and an external dynamic roller blind.

The control strategy of the external shadings was also energy efficient; the blinds and the external lamellas were set to be drawn whenever direct radiation of 50 W/m^2 hit the sensors on the façade. Furthermore the control strategy of the external dynamic blind was a cut-off strategy, meaning that according to the sun's position per different periods, e.g. summer-winter, the lamellas were inclined just as much as it was needed to block direct radiation from entering the rooms, thus allowing the maximum daylight possible in the occupied spaces.

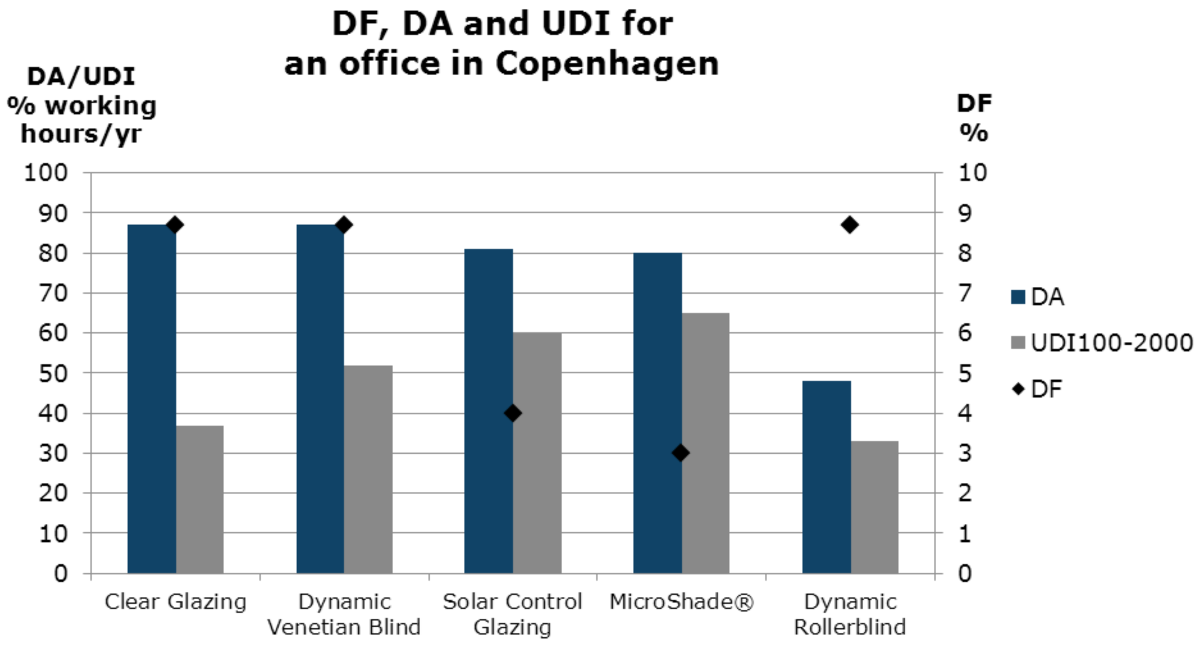


Figure 2. DF, DA and UDI for the five scenarios.

As a threshold for DA 200 lux was used, while threshold values of 100 lux and 2 000 lux was used for UDI. The results can be seen in **Figure 2**.

Looking at the graph above, it is noticeable that the two external dynamic shadings, the roller screens and the venetian blinds, have a DF equal to that of the clear glazing. That is explained by the fact that these blinds are automatically drawn when direct radiation of $50 W/m^2$ hits the work plane sensors, so by definition DF is not affected, since the blinds are not used under overcast situations. This is evident especially for the roller blinds, which seem to have a significant shading effect according to DA and UDI, but not according to DF. The latter also highlights that the daylight factor is not an appropriate metric to evaluate daylight when shadings are used.

What is interesting to note is that the application of the solar control and MicroShade glazing seems to level the percentage of daylight autonomy down by less than 10%. This implies that, although the drop in the daylight factor was 54% and 66% respectively from no shading to solar control and no shading to MicroShade, the DA metric shows that this merely affects the percentage of hours per year when the shading allows the room to be sufficiently lit by daylight alone even though they are permanent shadings.

UDI is the only metric that allows for the difference between the venetian blinds and the clear glazing to be evident, highlighting the value of the external lamellas cut-off strategy, which blocks all direct radiation and thus minimizes excessive illuminance levels for the time of year they are in use.

Traditionally external dynamic shading is seen as the best balance between daylight and energy, as they can maximize the utilization of daylight. However, in this example it is the MicroShade glazing and solar control glazing which gives the highest amount of hours with useful daylight. Why?

Figure 4 shows UDI$_{100}$, UDI$_{100-2000}$ and UDI$_{2000}$ for the five scenarios.

The reason why MicroShade provides useful daylight for a greater percentage of time compared to e.g. the venetian blinds is due to the increased exposure of the room to excessive illuminance levels with the latter. The illumination level exceeds 2000 lux for 38% of the working hours, while only 20% for the MicroShade glazing.

The chosen control strategy was, as earlier mentioned, a cut-off strategy for allowing maximum daylight. This strategy proved to give too much daylight. In reality it means that it is necessary to close the lamellas

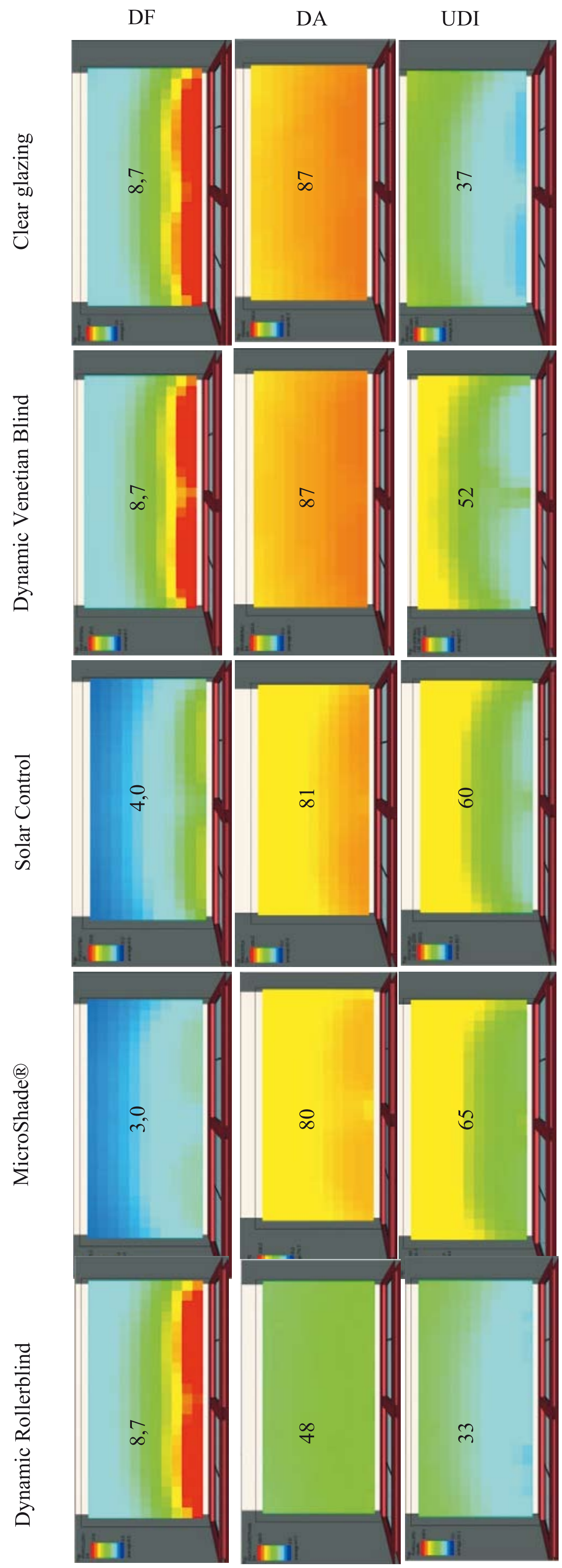


Figure 3. Distribution of DF, DA and UDI in the office.

An overview of the results would conclude the following from the perspective of each daylight metric alone:

DF - The dynamic blinds perform as good as the clear glazing does, whereas the permanent shadings; solar control glazing and MicroShade allows for the lowest illuminance levels in the room.

DA - All of the shading solutions with the exception of the roller blinds provide adequate daylight illuminance levels for a great percentage of the working year. The clear glazing and the dynamic venetian blind provides the highest amount of daylight.

UDI - The MicroShade glazing provides the highest percentage of working time with comfortable illuminance conditions for the occupants, which means adequately day lit and without glare, followed by the solar control coating, the venetian blinds, and the clear glass. The percentage of the clear glass is slightly higher than that of the roller blinds but for the opposite reason; the clear glazing allows for exceeding lux levels, whereas the roller blinds create a rather dark indoor environment.

Similar conclusions can be drawn by looking at the images below, which illustrate the distribution of daylight factor, daylight autonomy and useful daylight illuminance in the examined office space for the five scenarios.

more than just preventing the direct sun to enter. As in the case with the roller blind this can lead to more hours with illuminance levels below 100 lux, while also reducing the view out.

The external dynamic roller blind is the shading providing the most glare-free environment for the users. However, it shades so efficiently that for almost 50 % of the working hours the illuminance level is below 100 lux and there is a need for artificial light. The clear glazing has the exact opposite effect; there is only a need for artificial light in 10% of the working hours, while causing extreme illuminance levels (and a high risk of glare) for more than 50% of the working hours.

Current state of regulations

In the European committee for standardization - CEN – work is ongoing in TG169/WG11 for a proposal for a new standard for daylight in buildings. According to "A proposal for a European Standard for Daylight in Buildings" by J. Mardaljevic et al 7 the method is still based on the daylight factor, however a connection to the actual climate/location is taken into account.

Also in TC156/WG19 work is ongoing to revise EN15251. In the proposal8 a classification system for the daylight availability in a building is being established. The classification method is taken from

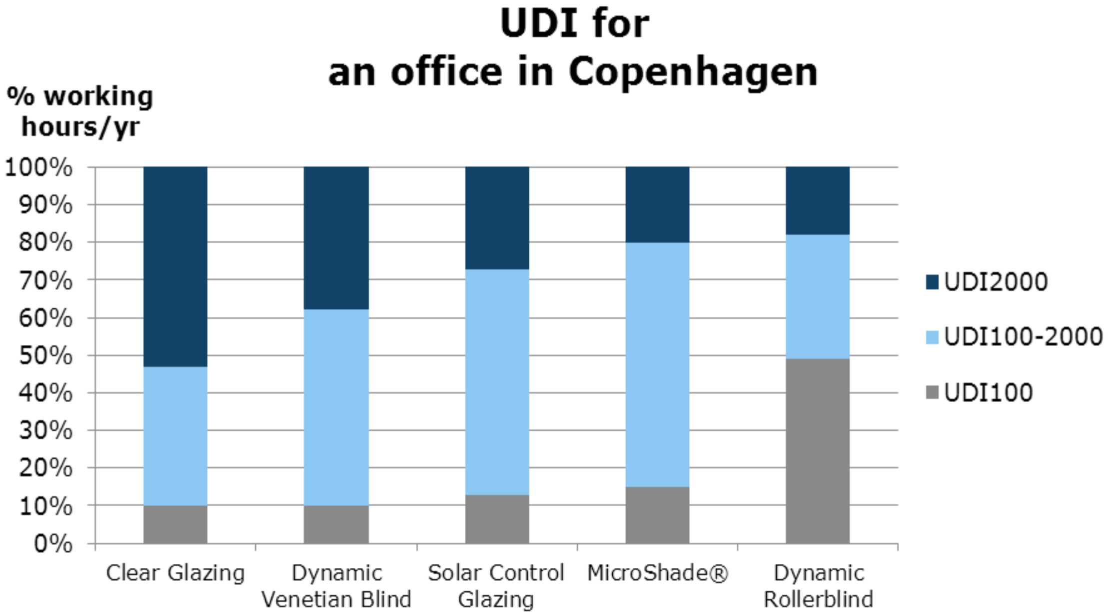


Figure 4. UDI_{100}, $UDI_{100\text{-}2000}$ and UDI_{2000} for the five scenarios.

ISO 10916:2014 and corresponds to the German standard DIN V 18599-4 for calculation of the impact of daylight utilization on the energy demand for lighting. The classification is also based on daylight factor.

So even though it is widely recognized by practitioners that the daylight factor method is not up to date it seems like it will take some time before the daylight factor is phased out.

Conclusion

Climate Based Daylight Modeling allows for informative analyses of daylight conditions in spaces by taking in account the location-specific climate characteristics of the building's position and showing the impact of the use of solar shadings. This is a feature lacking from the commonly used daylight factor analysis and it makes daylight assessments tailored to each building, whilst producing information on lighting energy savings, indoor illuminance conditions and occupant comfort.

The daylight investigation among the four shadings showed that the solution achieving the lowest daylight factor in the examined room, in this case the MicroShade, was actually the solution with the most hours/working year of useful illuminance levels and with adequate daylight autonomy. The example showed that accounting for the bespoke climatic annual conditions of the building as well as its location can alter the design decisions for improved daylight. It underlines the importance of using the right criteria in the design phase of a sustainable low energy building.

It is therefore recommended to use climate based daylight modelling in the design phase to secure the optimal utilization of daylight and at the same time secure good indoor climate and low energy consumption.

This requires a revision of the national building codes and international and European standards. ■

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5 http://www.usgbc.org/leed/v4/.

6 "Tutorial on the use of Daysim Simulations for sustainable design" af Reinhart C.F., 2010.

7 "A proposal for a European Standard for daylight in buildings" by J. Mardaljevic, J. Christoffersen and P. Raynham. CEN TC169/WG11.

8 "CEN TC156/WG19 Indoor Environmental input parameters for the design and assessment of energy performance of buildings" dated 17-09-2014.