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Evaluation of Daylight in Buildings in the Future

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Abstract

Building regulation requirements and traditional engineering practice for daylight calculations is often outdated and unsynchronized with the advance and needs of modern sustainable building design.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 different types of solar shading is examined.

Keywords:Daylight; Climate Based Daylight Modelling; Solar Shading; Legislation

1. Introduction

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.

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.

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 intensive 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 work hours during the summer in order to maintain a satisfying indoor climate. However, the daylight factor method does not take the solar shading into account and hence only represent less than 20% of the work hours.

Instead, there are by now several studies [1] [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 v4 [5] and has also been suggested as an alternative method in the proposal for a CEN standard on daylight (TG169/WG11) [8].

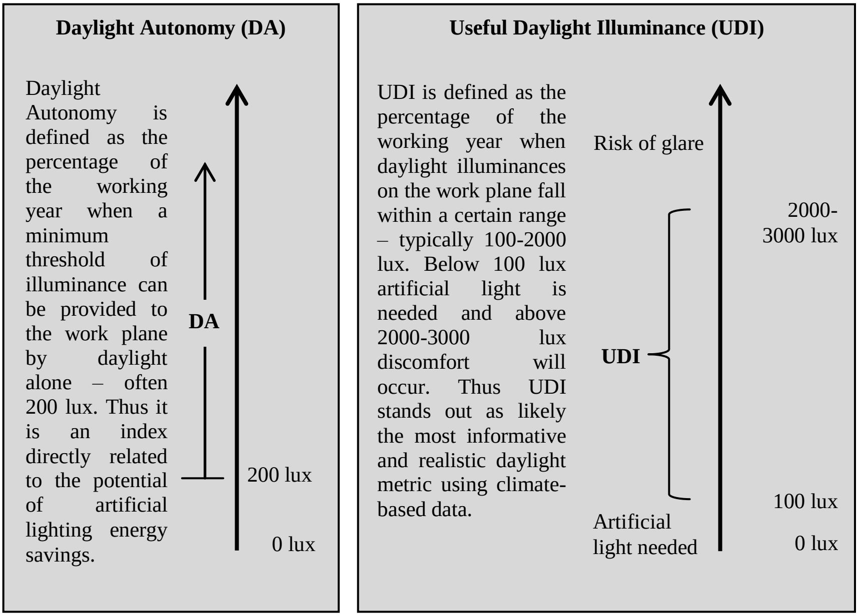
2. Method

Daylight Autonomy and Useful Daylight Illuminance

Daylight Autonomy (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.

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 2000-3000 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.

With a climate based daylight calculation it is furthermore possible to calculate the Daylight Glare Propability Index (DGP-Index) and estimate the percentage of people disturbed by high levels of vertical eye illuminance. [9] This was however not done in this study.



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 (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 2000-3000 lux discomfort will occur. Thus UDI stands out as likely the most informative and realistic daylight metric using climate-based data.

Fig. 1. Daylight Autonomy and Useful Daylight Iluminance.

The daylight factor, Daylight Autonomy and Useful Daylight Illuminance was calculated using DaySim for part of an open plan office in Copenhagen oriented south (Fig. 2). As a threshold for DA 200 lux was used, while threshold values of 100 lux and 2000 lux was used for UDI.

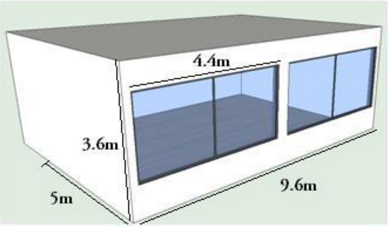


Fig 2. Office in Copenhagen facing south

The only parameter varying was the solar shading. Five scenarios were considered; 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. In table 1 the glazing specifications are given. The shading solutions were chosen based on their thermal performance as this is most often the case in building design.

Glazing specification	g_0	$L_{t,0}$	U-value (W/m^2K)
Low energy glazing (LowE)	0,53	0,71	0,70
LowE w/external dynamic lamellas	0,53 (0,14)	0,71 (0,16)	0,70
Solar control glazing (Suncool 40/22)	0,20	0,36	0,70
MicroShade® MS-A	0,35*	0,43	0,70
LowE w/external dynamic roller blind	0,53 (0,06)	0,71 (0,07)	0,70

Tabel 1. Glazing specifications. Numbers in bracket are with activated shading. *The g_0-value is not representative for the MicroShade® glazing due to the progressive nature of the product.

The control strategy of the external shadings was based on energy efficiency and thermal performance; 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 during summer, 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. The dynamic solutions were only used in the period March-August as this is the period it needs to be used in order to avoid overheating.

Dynamic Shading specification	Stages	Control strategy
External dynamic venetian blind	Slat angle 34°	Activated at 50 W/m^2
External dynamic roller blind	Open/closed	Activated at 50 W/m^2

Tabel 2. Dynamic shading specifications.

The MicroShade® has a progressive shading effect and thus the g-value varies with solar height and relative azimuth angle to the product. Hence the g_0-value does not represent the actual shading performance of the product. To compare MicroShade to the other shading products in relation to thermal performance it is necessary to calculate the effective g-value. In fig. 3 the effective g-value for the different shading solutions is shown.

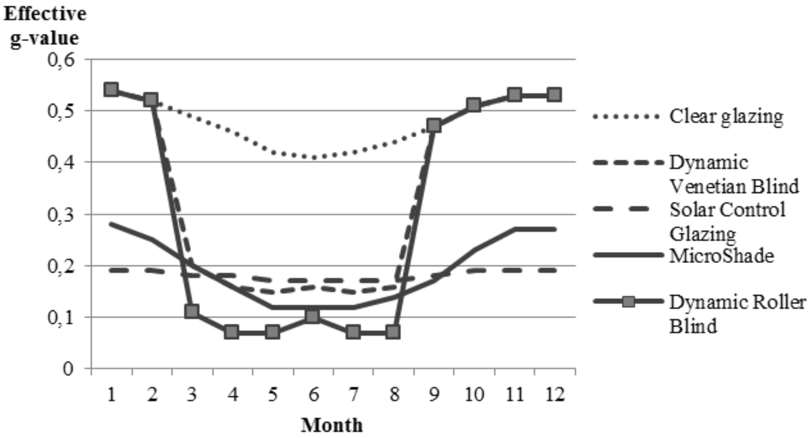


Fig. 3. Effective g-value of MicroShade®.

The four shading solutions have effective summer g-value varying between 0,08 for the roller blind and 0,17 for the solar control glazing.

3. Results

In Fig. 4. the Daylight Factor (DF), Daylight Autonomy (DA) and Useful Daylight Illuminance (UDI) is shown for the reference and four shading solutions.

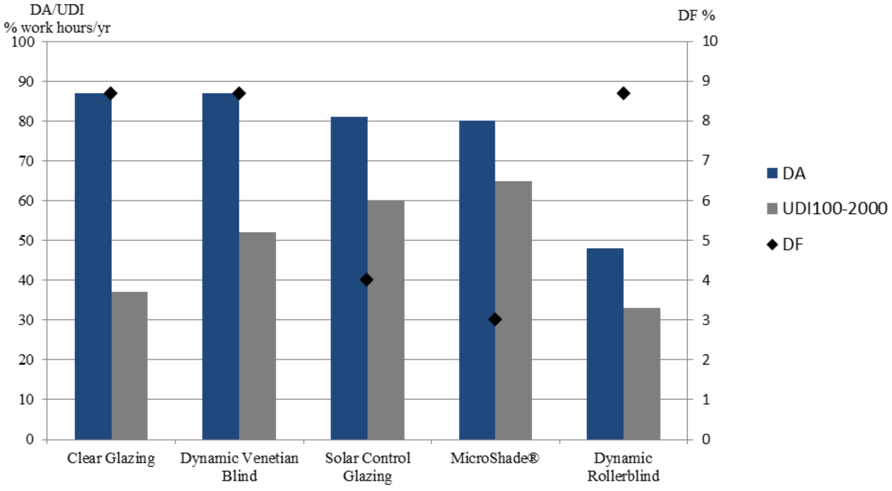


Fig. 4. DF, DA and UDI for the five scenarios.

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 DF does not take dynamic shadings into account. 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.

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 work hours during a year. The clear glazing and the dynamic venetian blind provides the highest amount of daylight.

UDI - The MicroShade glazing provides the highest percentage of work hours 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.

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? Fig. 5 shows UDI_{100}, $UDI_{100\text{-}2000}$ and UDI_{2000} for the five scenarios.

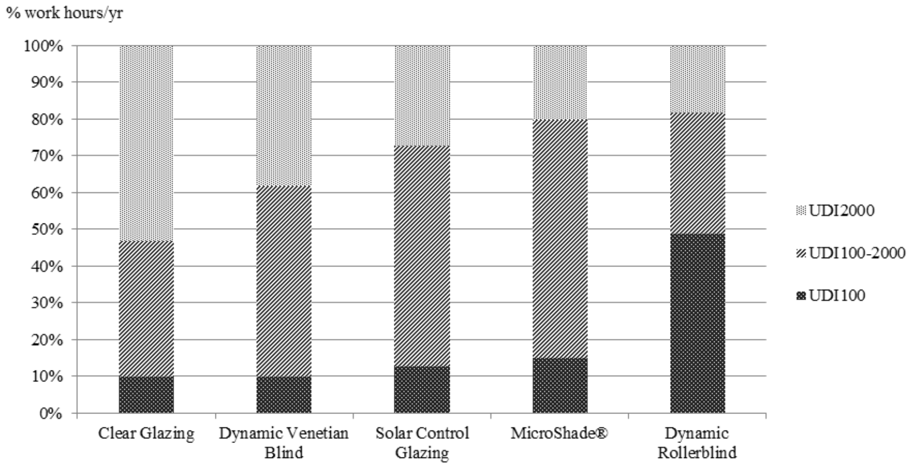


Fig. 5. UDI_{100}, $UDI_{100-2000}$ and UDI_{2000} for the five scenarios.

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 during March-August. This strategy proved to give *too much* daylight and due to visual comfort it is necessary also to use the blinds in the remaining year. 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.

4. Discussion

According to “A proposal for a European Standard for Daylight in Buildings” by J. Mardaljevic et al [7] the main method for evaluating daylight is still based on the daylight factor, however a connection to the actual climate/location is taken into account. Furthermore Spatial Daylight Autonomy (sDA) has also been proposed as an alternative method to daylight factor.

Also in TC156/WG19 work is ongoing to revise EN15251. In the proposal [8] a classification system for the daylight availability in a building is being established. The classification method is taken from 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.

5. 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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