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Modelling solar shadings with metallic slats for optimal daylighting. What parameters should we focus on?

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Abstract

Designing high performance buildings requires a proper consideration of solar exposures and indoor climate conditions so as to also achieve energy reduction targets. Solar shading systems with tilting metallic slats are commonly used to control light and energy transfer to the interior. However, a precise characterization of their performance has to include many parameters, which are not always easily available. Very often, component level metrics are used to compare solutions, but these are neither consistently related to a specific context nor they are reliable enough for more complex building envelope combinations. This study identifies the factors that most relevantly impact on the robustness of performance outcomes and focuses specifically on the scattering properties of metallic surfaces on simulation results.

Key Innovations

- Comparison of standard methods, up-to date building level simulation techniques and advanced optical simulation tools
- Detailed analysis of the sensitivity of various input parameters for optical performance of solar shading systems with metallic slats
- Measured scattering data are used in advanced optical simulations techniques.

Practical Implications

One of the most common challenges for building performance modellers is to choose the appropriate simulation method and tool for each application. However, little practical guidance is available to select a simulation strategy and workflow with respect to modelling solar shadings. This becomes particularly challenging when more complex systems are used. Simulations of daylight provision and energy transfer through building envelopes should strive to better integrate spatial distribution aspects. More precise models are required whenever relatively specular surfaces are used or for special slat profiles in shading systems.

Introduction

The building sector is accounted nowadays for up to 35% of global final energy consumption and for 38% of all energy-related CO_2 emissions (UN, 2020). Energy use for space cooling in Europe is still far below the share of heating, but these demands are expected to increase rapidly, also in temperate climates, based on current global warming trends (Dartevelle, 2021). For the residential sector, the additional electricity consumption, at the European scale, is estimated to be on average at 8,4% according to Jakubcionis (2017), with large variations between countries. We should avoid an upsurge of energy demands for cooling, particularly due to the increased diffusion and use of air conditioners, which could render useless many efforts on energy efficiency. Passive measures such as reducing solar gains with solar shading elements should always be a design priority.

Offering optimal thermal and visual comfort is a key issue for the occupants of buildings, also considering the more frequent and intense stress conditions resulting from current climate trends. In order to ensure our living and working spaces are fit for purpose, today as well as with respect to future climate conditions, a careful evaluation of comfort levels is required. Among others, Hamdy (2017) analysed overheating risks in Dutch dwellings and found that passive design and operation strategies – such as ventilative cooling and solar protections – can, in many cases, effectively suppress the effects of global warming without the need of active systems. Comfortable buildings can thus rely on optimised solar shading; to this aim, solutions and products using metalling slats are among the most common and effective options (Uribe, 2019).

Furthermore, we know that – other than providing suitable conditions for vision – daylight affects our physiological and psychological health (Knoop, 2019). Growing evidence confirms that the intensity, spectral, spatial and temporal dynamics of daylight are essential for our well-being, and in particular for the circadian entrainment of our metabolic functions (Houser, 2020). As in developed countries people spend most of their time inside buildings (Schweizer et al, 2007), it is important to improve indoor lighting exposure patterns, particularly during colder periods. Of course, issues related to thermal comfort also need to be considered. In any project, maximizing daylight provision should be balanced against risks of overheating and visual discomfort (e.g., glare). There is no unique and simple answer to this since, context, building functions and occupant requirements might substantially differ between projects.

A more precise evaluation of the design, functionality, and operation strategy of an essential building component such as solar shadings can provide a response to some of these challenges. The most common type of solar shading systems used in Europe consists of roller blinds made of

retractable fabric ('screens') or blinds consisting of stacked and guided metallic slats ('venetian blinds'). Standardized methods for characterizing the solar and optical properties of shading materials, glazing and other surfaces are extensively defined in European building standards (CEN, 2011; CEN, 2021), although improvements may still be required. Among these, the direct or normal-normal transmittance or reflectance properties of light-scattering materials and surfaces have been found to be sensitive to measurement parameters (Wilson, 2017). Complementary specifications have been introduced in the latest version of EN 14500 to improve the reliability of the measurements. Robust computational methods do not yet exist for shading and daylighting systems at building component level. Venetian blinds scatter radiation in multiple directions and strong angle-dependent properties can be observed. Multiple interactions at the edges of any shading system should also be evaluated in order to move away from the simple assumption of a 'centre-of-system' value.

Methods

A thorough comparative analysis of different evaluation methods and simulation tools for shading systems with metallic slats was performed in this study. The aim was to compare the results obtained within a dynamic building simulation process with respect to normalised calculation methods and advanced optical simulations techniques. We also investigated the sensitivity of the simulation results to a selection of input parameters.

As we focused this analysis on a quantitative evaluation rather than on qualitative user-centred aspects, we determined the total light flux on a vertical plane placed just behind the window system. The flux ratios in relation to a reference condition with glazing and no shading were then calculated, and these were used as a metric to evaluate the solar shading efficiency. This method of transmittance ratios is based on the fundamental definitions of transmittance applied to a combination of elements that constitute the building envelope. Analysis of the distribution aspects of light and radiation within the space, which are also essential to guarantee the visual comfort of occupants, were out of the scope of this study. To allow a consistent comparison between static and dynamic simulations, point-in-time calculations were used. This implies that intermediate calculation results from the dynamic simulation tool at specific time steps were extracted to estimate the variations with respect to static advanced simulations results.

Simulation and modelling parameters

In an extensive review of solar shading systems, Kuhn (2017) identified the main design parameters necessary to characterise a typical venetian blind. These include: slat width, slat distance (the ratio between slat width and their spacing), slat design (this includes the cross-sectional geometry and surface properties) and subdivisions of the curtain. Beside the intrinsic properties of the shading slats, the tilting angle and the exposure conditions (sky models and masking effects) can also have a substantial effect on estimated performance. In practice, however, input parameters such as the precise shape of the slats, the scattering properties of its surfaces, or the use of realistic sky luminance/radiance distribution patterns, are often fixed to generic settings or are simply disregarded.

Shading systems frequently exhibit non-regular light scattering or light redirecting properties (Andersen, 2005; Nilsson, 2010; Deroisy, 2013; Tzempelikos, 2016). This suggests that the *bi-directional scattering distribution functions (BSDF)* of the basic surfaces need to be determined and applied in the models. However, BSDF measurements are time-consuming and expensive. There is, therefore, very limited data available for most of the metallic surfaces used in typical shading products. Based on side-by-side experimental comparisons of an optical louver system and a typical venetian blind system Konis (2015) demonstrated the important variability of transmission and light distributions in a typical space and the potential of light redirecting systems.

Angular-dependent optical properties are another factor to be considered. For a large part of the day and the year, sunlight reaches the building envelope at angles that are far from normal incidence. Various algorithms, often based on Fresnel formulas, are used in simulation tools to adapt the properties measured in standardized tests environments to the actual conditions at each time step. These semi-empirical formulations, however, are only suitable for conventional glazing systems with regular optical properties. In his study, for example, Capperucci (2018) demonstrated that advanced fenestration systems, such as dye-doped liquid crystal (DDLC) windows in their bright state, substantially diverge from a typical behaviour. In this case, relative differences up to 30% in angular transmittance compared to a clear glass in the majority of the angular domain could result in a relative deviation of luminous transmittance ratios at façade system scale between 10% and 80% for a South-facing vertical façade (Capperucci, 2018).

The impact of sky models on daylighting simulations was demonstrated by Inanici (2017). A case with a South-facing façade consisting of clear glass and venetian blinds was assessed. Luminance distributions under different sky models with point-in-time simulations showed that sky models adjusted to the measured direct normal and diffuse horizontal radiation provide comparable results. The CIE sky models corrected to meteorological data seem to offer the luminance distributions that most closely match image-based models, used as a reference (Inanici, 2017).

In order to accurately predict the daylight transmittance and the energy flow through a complex fenestration system, many parameters are needed. For each application and purpose, a trade-off always needs to be found between accuracy, complexity, processing power and speed of calculation. For example, glare predictions are strongly sensitive to luminance values in specific regions of the field of view. Maximal luminance values can be substantially different in reality compared to the results obtained with most simulation tools (Jones and Reinhart, 2017).

A thorough review of recent relevant literature studies enabled to identify the main parameters to be adopted in this study in order to compare different assessment methods and simulation tools for these shading systems:

- *Sky model*: CIE Overcast sky or CIE Clear sky with various solar altitudes (15°, 30°, 45° and 60°);
- *Optical properties*: the total reflectance $\rho_{v,n\text{-}h}$ of the slat surface was set at values of 23%, 36%, 59% and 60%, with perfectly diffuse or irregular scattering properties;
- *Slat design*: The geometry of the cross-section of the slats was defined as flat (I-shaped), curved (C-shaped) or with a folded profile (Z-shaped);
- *Glazing type*: Standard low-e double-glazing unit (τ_v = 70%) and a clear double glazing with a higher transmittance (τ_v = 81%) were used.

A simple shoe-box volume with interior dimensions of 6.00 m x 3.60 m was assessed. The height of the interior space was fixed at 2.80 m. Two symmetrically-placed windows with dimension of 2.10 x 1.44 m were placed on a perfectly South-facing façade (Figure 1). The wall thickness was 0.40 m. Typical light reflectance properties for the surfaces of the window reveal (50%) and the ground albedo (20%) were chosen.

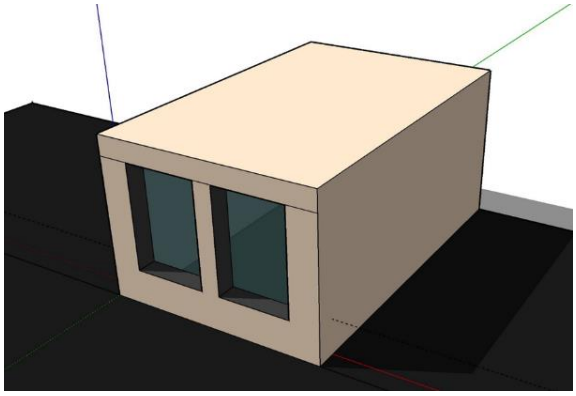

Figure 1: Shoe-box model

Each simulation case was modelled with the solar shading applied only to one window (*test case*), while the other unshaded window was used as a reference condition (*reference case*). The double glazing was placed at the centre of the window reveal and the central axis of the solar shading was located at a distance of 170 mm in front of the glazing. The shading slats were 80 mm wide and spaced between each other at the same distance. The tilting angles of the slats were set at 45°, 30° and 0° (horizontal). Higher tilting angles were not included in the analysis since, in these cases, most light and radiation would be reflected outwards and the different simulation and modelling parameters identified would no longer have any significant impact.

Three evaluation methods (phase 1, 2 and 3, described below) were used to evaluate the performance of the glazing combined with the solar shading element.

Standard method (Phase 1)

The standard method was based on the evaluation approach specified in the international standard series EN ISO 52022 (ISO, 2017a; ISO, 2017b). A distinction should be made between the simplified method of Part 1 (ISO 52033-1:2017), intended to give a quick estimate of the performance for product comparison, and the more detailed method of Part 3 (ISO 52022-3:2017), mostly used as input for energy performance calculation.

In these methods, the venetian blinds are treated as homogenous materials by their equivalent solar optical characteristics, depending on the angle of incident solar radiation. Only a limited set of conditions is proposed in these standards. In reality, the angle of incidence between the sun and the building façade varies continuously through time. The view factor method, as specified in EN ISO 52022-3:2017, was applied to calculate the total light transmittance of the combined glazing and solar shading system, and then the luminous flux ratio was determined.

Building performance simulation (Phase 2)

Building level simulation tools are generally used by designers and simulation practitioners to determine the most suitable shading element for a given condition, and a comparison of solutions is based on a narrow set of annual performance metrics (Brembilla et al., 2019).

The ClimateStudio software by Solemma LLC was used as the simulation tool for performing this building level analysis (Solemma LLC, 2020). This software allows to obtain, among other outputs, annual illuminance, glare and thermal comfort distributions in spaces within short calculation times. The tool uses Radiance and Energyplus as calculation engines with specific settings. Point-in time simulations for a set of specific clear sky exposure conditions were extracted for the purpose of comparison. Two approaches were taken for the daylight simulations: 1) the *physical model* approach; and, 2) the *BSDF* approach. In both cases, the glazing was positioned in the centre of the window reveal, and the reference analysis surface with sensors was placed vertically at the inner edge of the window wall.

In the *physical model* approach, the geometries for the various blind types at the specified tilt angles were imported as separate sub-layers, which could be toggled for each individual case. These sub-layers were placed at the outer edge of the window reveal. Radiance material properties were individually selected and applied in ClimateStudio. For both the test and the reference cases, the Radiance attributes for the separate DGUs were applied to the window planes.

In the *BSDF* approach, separate geometries were built in the Rhinoceros modeller for various blind types and were exported as OBJ files, for then being converted to RAD objects using OBJ2RAD in the Radiance command-line interface. Radiance materials were individually defined via text editing to the RAD files, which were then converted to BSDF XMLs using the genbsdf command. The BSDF XMLs of the shading systems previously generated were imported to the shading layer library panel, and were integrated to the DGUs in the Glazing

System library panel to create the composite BSDF for each case. In ClimateStudio, the investigated window plane was attributed the composite BSDF XML object representing the shading-glazing assembly. The sensors were offset by 0.01m from the vertical reference analysis planes (test and reference), and were spaced at 0.125m in either direction, thus creating 234 sensor points.

The weather file of London Gatwick was used for the analysis. The selection of the weather file was due to the need of using a location with a sunpath that, in the South direction, allowed solar altitudes ranging between (approximately) 15° and 60°, as per the defined settings. The ClimateStudio point-in-time illuminance simulations were performed under CIE Clear and Overcast sky models. Sample rays per sensor per pass were set at 64, the maximum number of passes was set as 25, and other Radiance parameters were set as follows: -ab 6; -lw 0.01; -ad 1. The mean illuminance values for the test and reference sensor planes were taken from the CS Results tab of ClimateStudio after each simulation run.

Advanced optical simulation (Phase 3)

For the most detailed evaluation, we used the industry standard optical engineering software, LightTools 9.1. This tool uses optimised raytracing techniques and allows to specify all the physical parameters for any optical system. For this study, the glazing was simulated with a constant refractive index of 1.52, neutral coatings, and a spectral variable extinction coefficient for clear glass (Rubin, 1985). For the solar shading, the exact geometry of the system was modelled. The possibility to integrate measured BSDF data was used to describe the scattering properties of the slat surfaces. The sky was modelled as a CIE Clear sky Type 12, with an average luminous turbidity factor T_v of 4.0 (Kittler 2018). The continuous sky model was built with data points at 5° angular resolution and interpolations for intermediate values. A preliminary analysis was made to identify the number of rays to be traced in order to reach reliable and stable results. For the complexity of the considered cases, 70 million rays in a forward raytracing mode were needed. According to these test results, an estimated accuracy below 2% on the vertical reference plane is expected.

Results

The results are given in this section individually for each parameter, although complex interactions occur when parameters are combined. The luminous flux ratios are calculated as the quotient of the total light flux on the vertical analysis plane of the test case and the reference case. Light transmittance values are expressed in relative ratios in order to counterbalance the effect of different assumptions on global illuminance (irradiance) from the sky model used in the various methods. The following sections focus on daylighting aspects.

Sky model

The solar altitude has a major impact on the total light flux entering a space. The more the shading slats are near to the horizontal position, the more radiation reaches the interior space either directly or by multiple reflexions on the slats and other surfaces, such as window reveals.

Under an overcast sky, the luminous flux ratio for a flat slat with 60% reflectance is 0.25 when the phase 2 method is used and 0.15 for the phase 3 evaluation method.

Under clear sky models, the solar altitude determines the power of the direct sun and of the diffuse sky radiation components. Figure 2 shows a comparison of luminous flux ratios between building performance simulations (Phase 2) and advanced optical simulations (Phase 3) for perfect diffuse scattering properties of the slats. In the Phase 3 evaluations, the metallic slats were modelled as a Lambertian surfaces. The physical model approach is shown here for the Phase 2 evaluations. The results are relatively consistent at low (15°) and high (60°) solar altitude (shown on the x-axis), but larger variations can be observed for intermediate solar altitudes (30° and 45°). When the slats are tilted at 30°, and for an exposure condition corresponding to a CIE clear sky with a solar altitude of 30°, the luminous flux ratio difference for Phase 2 is 0,13 or 46% lower than the value obtained with detailed optical simulations (Phase 3).

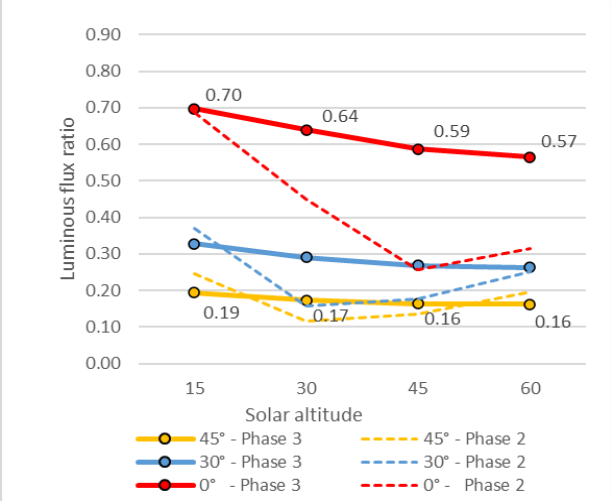

Figure 2: Luminous flux ratios for tilt angles positions – Comparison between Phase 2 and Phase 3 evaluations

Table 1 provides the results for the luminous flux ratios calculated for one type of measured slat surface properties (BSDF Type 2). The luminous flux ratios are different when slats with more specular finish are used (Table 2).

Table 1: Luminous flux ratios in function of solar altitude for a slat surface BSDF Type 2

	Solar altitude			
Tilt angle	**15°**	**30°**	**45°**	**60°**
Phase 1 - Standard method				
45°	/	/	0.270	/
Phase 2 - Building performance simulation				
45°	0.245	0.117	0.136	0.195
30°	0.370	0.158	0.177	0.251
0°	0.688	0.450	0.258	0.316
Phase 3 – Advanced optical simulation				
45°	0.207	0.186	0.174	0.172
30°	0.346	0.307	0.284	0.277
0°	0.733	0.677	0.625	0.602

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It should be noted that the value obtained with the standard method (Phase 1) is overestimated compared with the other more detailed assessment methods for the specific reference situation of this standard value (45° tilt angle and 45° solar altitude). However, if the light transmittance obtained with the standard method is used as a unique approximated value for the daylighting performance of the solar shading, this is on the lower range of possible values.

Scattering properties

The scattering properties of metallic surfaces can vary largely. In general, most commercially available metallic slats for solar shadings have relatively regular properties, but with a strong specular component. Measurements realised with a photogoniometer on a set of 6 typical slat surfaces confirmed the rotational symmetry around the specular reflection, which allows to represent BSDF data in a 2D section (Figure 3). Two families of scattering distributions could be identified. The first has a relatively small specular peak but an irregular diffuse component (Type 1). The second has a wider specular peak and a nearly constant diffuse component (Type 2). The surface properties of the BSDF Type 1 reflect the radiation much more in preferential directions than the Type 2, especially at lower angles of incidence.

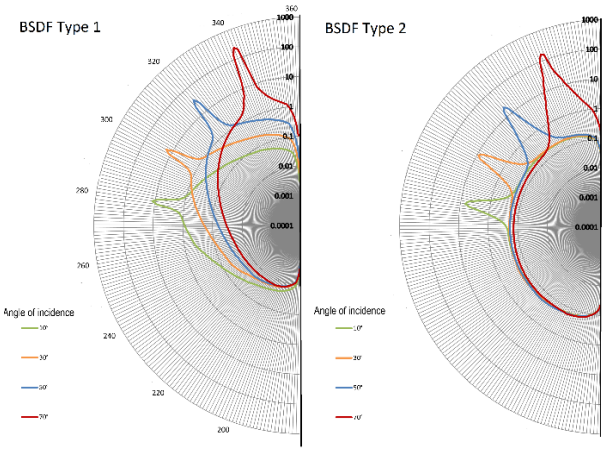

Figure 3: BSDF data for two typical slat types measured at incidence angles of 10°, 30°, 50° and 70° (The radial axis has a logarithmic scale)

If we compare slats with an identical hemispherical reflectance value of 60% (Table 2), but with different scattering profiles, we first observe that calculating with the BSDF-based properties results in higher luminous flux ratios than a simple Lambertian diffuse model, whatever the combination of slat tilt angle and solar altitude. Secondly, the BSDF Type 1 slats redirect the radiation more towards the interior and, consequently, the luminous flux ratios are higher, especially when the solar altitude is low. The general trends are similar for the tilt angles of 30° and 45° when the evaluation is made with the advanced optical simulation method (Phase 3). For a horizontal position of the slats (0°), the effect on the transmitted light flux is highest at 45° sun angle. Indeed, when the sun is at higher altitudes, the upper face of the slats are not fully lit by direct sunlight.

Table 2: Relative differences of luminous flux in function of optical properties of slats and solar altitude (Phase 3)

	Solar altitude			
Tilt angle	**15°**	**30°**	**45°**	**60°**
Tilt angle 45°				
Type 1	**12.8%**	9.6%	4.6%	1.1%
Type 2	**7.0%**	6.9%	6.3%	5.9%
Tilt angle 30°				
Type 1	**13.8%**	13.2%	10.6%	7.6%
Type 2	**5.5%**	5.5%	5.5%	5.4%
Tilt angle 0° (horizontal slats)				
Type 1	7.7%	10.1%	**12.1%**	10.0%
Type 2	5.0%	5.8%	**6.5%**	5.8%

Slat design

The individual slats for solar shading systems intended for external applications are very often curved. In this study, we compared the effect of a flat slat profile with a curved (C-shaped) and a folded profile (Z-shaped) (Figure 4).

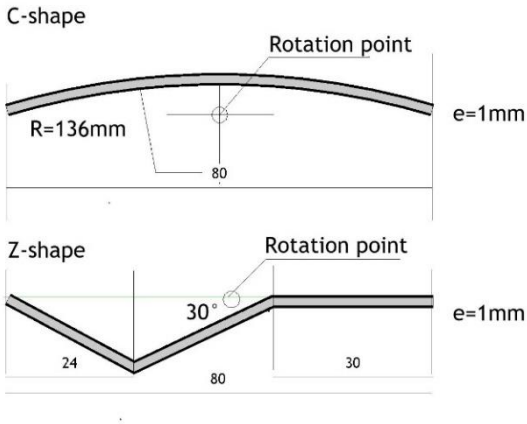

Figure 4: C-shaped (top) and Z-shaped (bottom) slats

The radius for the C-shaped slat is 136 mm, which corresponds to 1.7 times the width of the slat. The flat geometrical shape of the slat (I-shape) has no detectable influence on the total light transmittance through the system compared to a C-shaped slat. However, a typical Z-shaped slat increases the light transmittance by at least 10% compared to a curved slat and the impact increases at higher solar altitude (Table 3).

Table 3: Relative difference of the luminous flux (Phase 3 assessment) depending on slat design, with slat tilt angle of 30° ,CIE clear sky and different solar altitudes

Slat type	15°	30°	45°	Average
I-shape	-1.0%	-1.1%	-0.9%	**-1.0%**
Z-shape	11.9%	13.3%	16.0%	**13.7%**
Z-shape*	10.7%	13.8%	18.7%	**14.4%**

*Slats with specular surface finish on the outer tip of the Z-shape

These patterns could not be consistently observed under the building performance simulation evaluation realised in Phase 2. Flat slats clearly outperform the curved slats in Phase 2 evaluations, with at least 30% higher luminous transmittance ratios. Conversely, Z-shaped slats present values that are sometimes higher sometimes lower.

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Further aspects could be observed when combining the shaping of the slats with different scattering properties for upper and lower surfaces, or for parts of the slat surface. If the outer tip of the Z-shaped slat is made with a strongly mirror reflecting surface, the light transmittance can be further modulated (Table 3). For a low solar angle of 15°, the specular reflections on the outer tip of the profile are redirected to the outside, this leading to a reduced transmittance. When the solar altitude is 30°, the specular reflected light on the outer tip of the Z-profile is mainly directed upwards to the lower surface of the slat above, and then partially reflected inwards. When the solar altitude is higher than 30°, the specular reflections are pointing directly inwards, this having a more important effect on light transmittance.

In this example, we applied the specular finish only on the tip of those slats that are above the typical eye height of an observer in the room. This allows to reduce the risk of glare, because the sunlight is always reflected to the ceiling. Figure shows the illuminance distribution on the vertical reference plane for both options. A strong illuminance can be seen on the upper part due to the specular reflections.

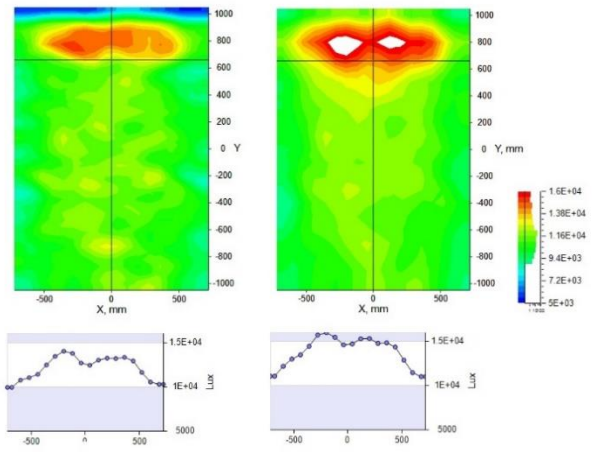

Figure 5: Illuminance map on the vertical reference plane for a shading system with Z-shaped slats (left) and Z-shaped slats with a specular tip (right) (Phase 3)

Glazing type

Glazing types used in buildings can vary considerably in their light transmittance properties. The simulation results show that the effect of glazing type is proportional to the light transmittance value determined at normal incidence. For the two cases studied (Clear and low-e DGU), a reduction in light transmittance from 81% to 70% resulted in a difference of luminous flux ratio between 12% and 13%, depending on solar altitude. Most clear double or triple glazing units have regular optical properties. For daylight simulations of transparent and spectrally neutral glazing types, the normal transmittance value is, therefore, sufficient as modelling input. However, all glazing types with highly spectrally selective properties or specific scattering surfaces should be evaluated with adequate methods.

Discussion

This study has investigated the main factors affecting the performance outcomes of daylighting simulations for a typical solar shading with metallic slats.

Out of the four simulation parameters considered (sky model, optical properties, slat design, glazing type), the factor that has the largest effect on the consistency of simulation outcomes is represented by the tilt angle of the slats. An adequate and accurate setting of the tilt angle, based on solar altitudes and internal requirements, is essential to guarantee comfortable conditions for users at any time. This possibility of adjusting the performance is one of the main advantages of shading systems with metallic slats, and control strategies should be able to exploit this potential. Also, the light scattering properties of the slat surfaces have a non-negligeable impact on performance. Real slats are often relatively specular. Modelling them as perfect diffuse surfaces generally underestimate transmittance ratios when the system is in a relatively open position. The shape of the slats can also have a significant impact when special slats are used, such as in Z-shaped folded profiles. The difference between a flat slat and a typical curved slat is not detectable with advanced optical simulation techniques, so flat slats could be used in order to simplify the modelling process.

Although this analysis included consideration of all the parameters that are more frequently featured in relevant studies from the literature, some other factors could not be taken into account. For example, the shape of the window reveals and their finishes could have an important impact on the daylight provision in a space.

Regardless of these methodological limitations, this study can offer some useful information to simulation practitioners in order to adequately estimate the performance of typical shading solutions and identify the limit of application of conventional evaluation methods. In fact, current simplified transmittance models that do not consider spatial distribution properties may result in considerable differences in performance evaluations, especially for shading systems using metallic slats. In early design stages the transmittance value obtained according to the detailed standard method of EN ISO 52022-3 could be used as an estimate but in later stages of the design and when comfort parameters are to be assessed a detailed simulation model using scattering distribution properties should be used.

Further research is particularly needed to robustly determine the effect of special or atypical solar shading solutions aiming to redirect light in preferred directions. These systems include, among others:

- Shading systems with highly angular-dependent properties (e.g., strongly specular slats, slats with an irregular profile geometry, prismatic panels, etc.)
- Façade systems with glazed or opaque components characterised by significant spectrally-selective transmittance or reflectance

properties (e.g., solar coatings, tinted glass, coloured or textured surfaces, etc.).
- Innovative transparent, semi-transparent or diffusing panels (e.g., electrochromic glazing, glazing with integrated solar cells, etc.).

Complementary work to specify BSDF characterization methods and their requirements is currently being done in subtask C of the International Energy Agency Task 61 / Annex 77 focusing on integrated solutions for daylighting and electric lighting (IEA, 2020).

Furthermore, it is expected that research on the non-visual effects of daylighting will gain substantial importance in the coming years. If the circadian effects of light are to be considered, then fully spectral daylight simulations will be required. In this context, Balakrishnan (2019) demonstrated that non-spectral standard RGB daylight simulations do not offer reliable results to properly estimate the effects of direct and reflected light on the entrainment of our non-visual system.

In a broader perspective, the selection of a solar shading system will also depend on numerous other factors, including external obstructions, the characteristics of the space, internal heat gains, daylight targets, view out and control strategies. Protecting window surfaces from excessive solar radiation in warmer periods of the year, while facilitating solar ingress at colder times, yet properly managing the risks of visual discomfort, should be the primary target of any daylighting project. In response, movable shading systems should offer an optimal solution. Many studies, however, have shown that the potential of movable shading are seldom fully exploited due to the limited interactions from the part of the occupants. This has been observed in office environments as well as in residential applications (e.g., Verbruggen, 2020). Other than accurate information on the performance evaluation of the shading systems, the implementation of better control and operation strategies are equally important.

Conclusion

The results of this study allow to identify the simulation and modelling parameters that should be primarily considered when evaluating the daylighting performance of a building envelope with solar shading systems. This is particularly important at design stage, when plausible initial simulation outcomes are crucial to drive decisions between alternative solutions. The results with any evaluation methods only relying on the values determined on the basis of current standards should be handled with caution. Large differences were observed between values obtained with the two simulation-based methods for medium sun angles. The current building simulation applications do not allow to accurately estimate the impact of special slat profile shapes on daylighting performance. The need for yearly-based computations, and the associated use of annual metrics, is pushing building simulations towards a relative simplification of their calculation processes. However, there is a risk that this could make objective evaluation of more complex building envelope systems in relation to daylighting more difficult, as well as in terms of thermal comfort and energy performance predictions.

The conclusions from the daylighting simulation could be transferred to radiative heat transfer only if spectrally neutral materials are used. Modelling methods using perfectly diffuse scattering properties for the slats will tend to underestimate the solar gains and are, therefore, not fully reliable to assess risks of overheating.

In many building projects, balancing daylight provision, visual and thermal comfort, while ensuring a reduction of energy use, is a serious challenge. Since the risks of thermal discomfort might significantly increase with the current trends of global warming, it is necessary that the current emphasis on energy reduction targets be properly supported by robust and consistent consideration of indoor climate conditions.

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