Opportunities and Challenges for Performance Prediction of Dynamic Complex Fenestration Systems (CFS)

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Abstract
This article presents an overview of possibilities and points of attention for modelling the performance of dynamic CFS in building performance simulation software. Following a detailed analysis of the unique requirements that are associated with modelling of CFS, a comparative study of the capabilities in different software implementations is presented. In addition, we present on overview of state-of-the-art approaches to obtain the necessary Bi-directional Scattering Distribution Functions (BSDF), involving experimental characterisation, databases, and component-level ray-tracing approaches. The second part of the paper provides a detailed discussion of a case study of a high reflective lamella system. This case study complements the review with hands-on information from a practical example and highlights the importance of developing models at the right level of complexity, taking into account the type of questions that the simulation intends to answer and the required accuracy level to do so.

Keywords
Complex Fenestration Systems (CFS), building performance simulation, bi-directional scattering distribution functions, reflective lamella, modelling complexity

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1 INTRODUCTION

Contemporary building facades are expected to be increasingly multi-functional. They should not only provide shelter and protection, but often simultaneously also take care of energy conservation, daylight admission, glare prevention, and mitigation of overheating. In response to these high-performance requirements, a growing interest in façades with light redirecting elements, or layers with light scattering properties, can be observed (Appelfeld, McNeil, & Svendsen, 2012; Gong, Kostro, Motamed, & Schueler, 2016; Saini, Loonen, & Hensen, 2018; Vera, Uribe, & Bustamante, 2017). Examples include venetian blinds, glass frits, prismatic films, etc. Unlike conventional glazing, these systems usually exhibit non-specular transmission. Moreover, their transmission properties idiosyncratically depend on the position of the sun or wavelength of the incoming radiation. To distinguish these fenestration systems from specular glazing types, they are often referred to as Complex Fenestration Systems (CFS) (Fig. 1).

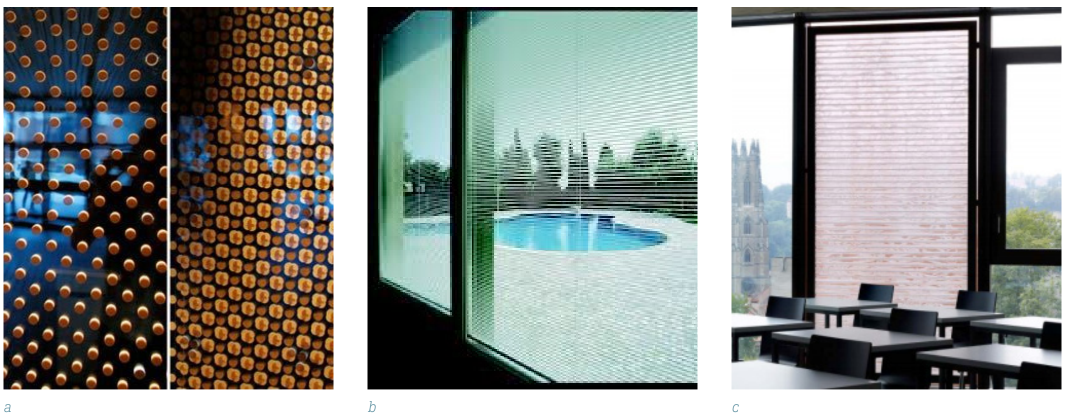

FIG. 1 a) Adaptive Fritted Glass, Adaptive Building Initiative *(http://www.hoberman.com/abi.html accessed in May 2018)*; b) IGU Cavity integrated solar shading lamellas *(https://performanceglass.co.uk/pellini-blinds/venetian-blinds/ accessed in May 2018)*; c) Prismatic PCM system, GlassX *(http://glassx.ch/index.php accessed in May 2018)*

The product development of such innovative façade systems can greatly benefit from inputs obtained using building performance simulation tools (Loonen, Singaravel, Trčka, Cóstola, & Hensen, 2014). Such computational tools can also aid in the adoption of CFS in new buildings, by providing opportunities for informed design decision-making from the planning phase itself.

A number of requirements are associated with modelling and simulation of CFS, deriving from their physical characteristics:

- The optical properties of CFS tend to have a high solar angle dependency.
- Many CFS involve scattering/diffusing layers that can be difficult to characterise. Some CFS involve materials (e.g. Phase Changing Materials, PCM) that have a special impact on the heat transfer characteristics of the façade component.
- The three-dimensional shape of optical elements (e.g. lamellas) in CFS can introduce unconventional physical effects.
- CFS are often part of an adaptive façade system, i.e. they can be controlled by varying the component's physical properties to meet different performance requirements. In such situations, it is important to take appropriate façade operation strategies into account in the models (Loonen, Favoino, Hensen, & Overend, 2017).

Because of these considerations, standard simulation workflows might not always provide sufficient flexibility to carry out the task at hand, leading to the need for dedicated models at a higher resolution. When intending to use or develop such detailed models, one should be aware of potential pitfalls and other points of attention. However, in academic literature and software manuals, there is very little attention given to best-practice advice and practical considerations for performance prediction of buildings with CFS.

The objective of this article is, therefore, to compile and present an overview of possibilities and points of attention for modelling the performance of dynamic CFS in building performance simulation tools. Following a detailed analysis of the unique requirements that are associated with modelling of CFS, a comparative study of the capabilities in different software implementations is presented. In addition, we provide an overview of state-of-the-art approaches to obtain the necessary Bi-directional Scattering Distribution Functions (BSDF) for quantification of optical properties of CFS, involving experimental characterisation, databases, and component-level ray-tracing approaches. A case study of a high reflective lamella system is discussed in detail, to complement the review with hands-on information from a practical example.

2 ADVANCED SIMULATION MODELS FOR CFS

2.1 REQUIREMENTS

Due to their intrinsic properties, CFS influence the characteristics of transmitted solar radiation (visible and non-visible). As a result, the main challenges for accurate performance prediction of CFS using building performance simulation (BPS) tools lies in:

- achieving an appropriate representation of two-dimensional angular dependency (on solar geometry and/or control of the components) of optical properties of the fenestration system, such as visible transmittance;
- achieving an appropriate representation of two-dimensional angular dependency (on solar geometry and/or control of the components) of thermal properties of the fenestration system, such as solar heat gain coefficient;
- implementing a control logic (either intrinsic or extrinsic) during the simulation run-time in the case when CFS are part of an adaptive façade system. This is because when façade properties vary over time, the amount of solar radiation that enters the zone also varies, leading to a different thermal response of the space;
- taking into account the interactions between both visual and thermal physical domains to predict the performance of such fenestration elements in an appropriate way.

2.2 DEFINITION OF BSDF DATA

The most commonly-used way of representing the two-dimensional angular dependency of solar properties (transmission and reflection) of CFS is via Bi-directional Scattering Distribution Functions (BSDF). The BSDF method was proposed by Klems (1994) to calculate solar transmission of multi-layered CFS through matrix multiplication. In this method, the front and back hemisphere of the CFS layer is discretised into 145 patches; for each of these, optical properties are specified depending on azimuth and altitude angles. The BSDF dataset-containing file describes the transmission (Bi-directional Transmission Distribution Function, BTDF) and reflection (Bi-directional Reflectance Distribution Function, BRDF) properties of a complex glazing system by a 145 x 145 matrix, according to incident and outgoing angles using Klems' angle basis (Fig. 2).

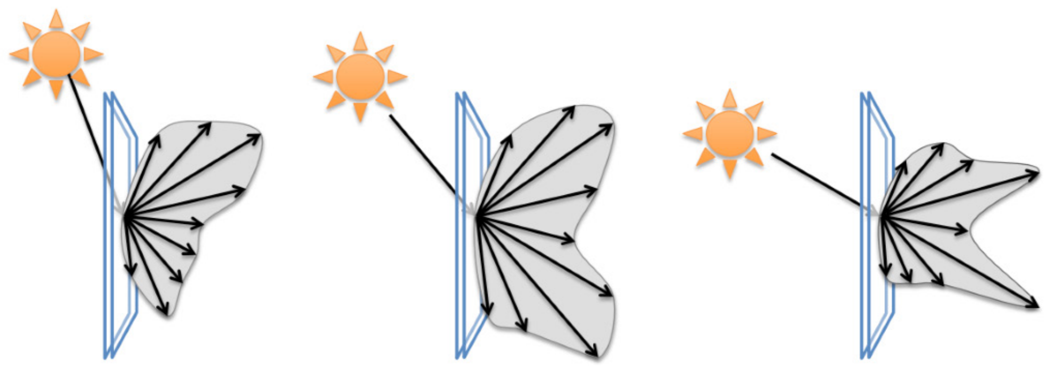

FIG. 2 A BSDF file describes the directional transmission and reflection for many different combinations of ingoing and outgoing directions. *(Image by Christian Kohler, LBNL)*

2.3 REVIEW OF MODELLING OF CFS IN BPS TOOLS

Generally, BPS tools only offer the possibility of considering one domain at a time, either thermal or visual.

As far as BPS tools that allow the evaluation of whole building energy performance by means of thermal networks (i.e. Energy Plus, TRNSYS, ESP-r, etc.) are concerned, the main practice, while considering the thermal and optical properties of a complex fenestration system, is to use calculation algorithms according to ISO 15099 for the layer-by-layer heat transfer. In the ISO 15099 standard, the analytical algorithms for the optical modelling are restricted to simplified models, developed for planar or curved blinds that behave as ideal diffusers. For this reason, the algorithm relative to the optical modelling has been fully replaced with BSDF data in most of these BPS tools:

1 EnergyPlus: Since version 7.2, the BSDF functionality has been part of EnergyPlus as one of the optical representations of fenestration systems. This implementation relies on the strong integration between EnergyPlus and Berkeley Lab WINDOW (or WINDOW) (Berkeley Lab, 2007) software that allows the export/import of .idf files. The Construction:ComplexFenestrationState (US Department of Energy, 2010) can be controlled during simulation run-time, by making use of the EMS (Energy Management System) functionality. Additionally, EnergyPlus offers the possibility to define specific external schedules for solar transmission and solar absorption of CFS. In recent work, Hoffmann, Lee, & Clavero (2014) used this approach for pre-calculating the two schedules, for different shading systems, by using Radiance. The BSDF function is also integrated in COMFEN, a user-friendly interface to the EnergyPlus/Radiance engines.

2 ESP-r: ESP-r is the only tool with an in-house developed model for complex fenestration systems, based on the AGSL shading model; not BSDF. It is aptly named the CFS functionality (Lomanowski & Wright, 2012)the Complex Fenestration Construction (CFC. Alternate property sets for different fenestration/shading states can easily be changed using TMC control or the BCVTB-ESP-r control functionality (Hoes, Loonen, Trčka, & Hensen, 2012). An alternative approach called the "black-box model" was developed by Kuhn, Herkel, Frontini, Strachan, & Kokogiannakis (2011), who proposed a new methodology for the evaluation of solar transmission of the complex system. This approach simplifies the modelling part and does not require many measurements. The model takes as input measured or analytically derived total solar energy transmittance (gtot), total solar transmittance (te tot), and total solar reflectance (re tot) for different angles of incidence. Then, the model introduces the radiant and convective effect of solar heat gains into the energy balance of the building through a two-layer approach. Other applications of the model are reported in (Frontini, Kuhn, Herkel, Strachan, & Kokogiannakis, 2009).

3 Fener: Fener is a dedicated tool that was developed to ease the modelling and simulation of CFS systems (Bueno, Wienold, Katsifaraki, & Kuhn, 2015). It combines Radiance with a reduced-order RC network approach for thermal calculations on a time step basis. One of the specific strengths of Fener is its flexibility for implementing shading control algorithms, based on, for example, daylighting variables such as illuminance and glare, thermal variables such as indoor temperature and energy load, or weather variables such as wind and solar radiation.

4 TRSNSYS: A new TRNSYS type for daylight performance prediction with BSDF systems has recently been developed at Eurac Research (TypeDLT) (De Michele, Filippi Oberegger, & Baglivo, 2015). These daylight predictions can be coupled with the multi-zone thermal model (Type 56). Since version 18, bi-directional thermal properties, according to ISO 15099, can also be calculated in TRNSYS's thermal building model (Hiller & Schöttl, 2014).

The main and most accurate BPS tool that allows evaluation of the performance of the built environment in the visual physical domain (adopted as a calculation engine in many interface softwares) is Radiance (Ward, 1989). In particular, the multi-phase matrix-based methods (e.g. three-phase and five-phase) are useful in the present context, because of the possibility for annual evaluations (Subramaniam, 2017). All the matrix methods use common input data to describe the light passing through the CFS, which is the BSDF. Differently from the thermal analysis, in the daylighting analysis it is also possible to employ high resolution BSDF (tensor tree resolution) mainly for glare analysis and the calculation of the Annual Sunlight Exposure (ASE) index (IES, 2012).

3 SOURCES OF BSDF DATA

3.1 COMPLEX GLAZING DATABASE

BSDF files (in XML format) for a variety of window materials and daylighting systems can be obtained from the LBNL complex glazing database (CGDB). This resource contains more than 100 systems, such as shading devices and materials (e.g., venetian blinds, roller shades, drapes, cellular shades, shade fabrics, etc.), light redirecting materials (e.g., prismatic films, etc.) and scattering glazing (e.g., diffuse glass, glazing frits, decorative glass, etc.). With this database, customised multi-layer glazing systems for different configurations of a façade system (e.g. shades up, down, and/or tilted) can be created using the Berkeley Lab WINDOW program. From this program, data files can be exported for use in a number of whole building performance simulation programs.

Especially when innovative fenestration systems are considered, it may happen that the optical behaviour of the fenestration system is not yet available in the CGDB. In this scenario, two options are available to obtain the necessary bi-directional optical data: i) experimental characterisation or ii) modelling/simulation.

3.2 MEASUREMENTS

Photometric equipment, such as a goniophotometer, is needed to characterise the angular transmission and reflection properties. This equipment is available in only a few research labs around the world. Experimental characterisation is practically possible for small-scale CFS with homogenous scattering properties.

3.3 SIMULATIONS

For macro-scale CFS with complex geometry e.g. louvres and specular blinds, the incident light source of photometric equipment cannot sufficiently take into account variations in CFS. BSDF files for such systems can be created by applying radiosity or ray-tracing algorithms on a geometrical model of the shading system or daylighting device in WINDOW or TracePro/genBSDF, respectively. For a simplified geometrical model and Lambertian systems, WINDOW can be used, while for complex geometries and/or non-Lambertian surfaces, TracePro or genBSDF should be used. TracePro is a commercial software with a 3D CAD-based graphical user interface for design and analysis of optical and illumination systems. genBSDF, part of the Radiance daylight simulation suite, is a free and open source tool that generates a BSDF file from a Radiance or MGF scene description (McNeil, Jonsson, Appelfeld, Ward, & Lee, 2013).

3.4 COMBINE MEASUREMENT AND SIMULATIONS

It is possible to extend the simulation method with detailed measured data of the shading material. For this specific application, the opaque material reflectance can be characterised either through a spectral curve (Fig. 3 a) or BRDF (Figs. 3 b and c). The spectral curve method is a hemispherical measure of the material reflection, which is reliable for materials that behave or can be assumed as Lambertian; while the BRDF is suitable for materials whose reflection presents complex behaviour (e.g. high reflective or retro-reflective material) and an angular distribution is required.

In order to use the spectral data within WINDOW and Radiance, it has to be integrated on the solar and visible ranges. The integrated values are directly set in the WINDOW material library, while in Radiance, they are adopted by using the plastic material. Then, the material has to be applied to a geometry that represents the shading device. Regarding the BRDF, such data can be used in Radiance by applying the BSDF material to a 3D geometry using genBSDF to generate an xml file of the shading device. This xml file can then be imported in WINDOW as a shading layer where it can be directly joined to the glass layers in order to generate the BSDF of the whole system.

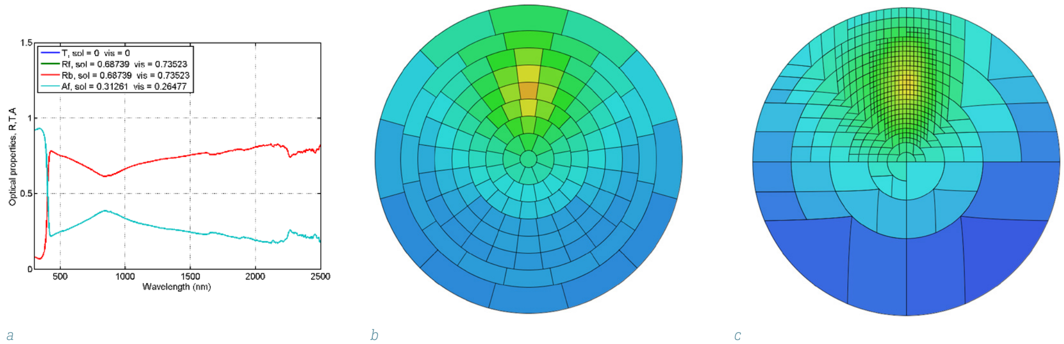

FIG. 3 a) is an example of spectral reflection curves of an opaque white material; b) and c) are two measured BRDF respectively on Klems and tensor-tree base.

4 PERFORMANCES EVALUATION OF HIGHLY REFLECTIVE LAMELLAS

In this section, the modelling and simulation of a CFS is presented. The shading system is a curved lamella characterised by a highly reflective coating. In order to show the impact of correct modelling of the shading system on the energy and daylighting results, two models of the same shading system are compared.

4.1 MODELLING OF THE SHADING SYSTEM

The shading device is a curved commercial blind produced by Pellini ScreenLine®. The blind is coated with a highly reflective layer. Two fixed shading configurations with 15° and 30° blind tilt angles have been considered in these simulations. Geometrical dimensions are reported in Fig. 4 and Table 1.

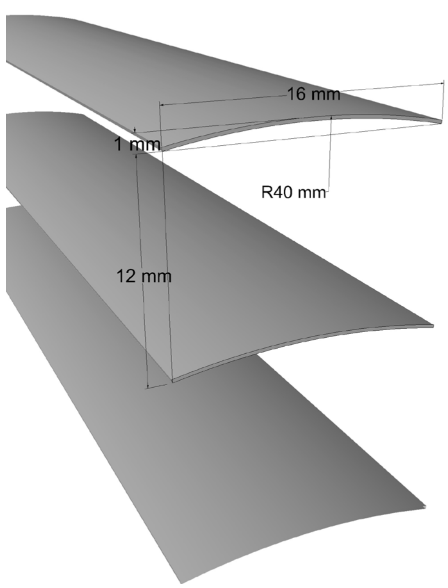

FIG. 4 3D geometry of blind

Blind width	16	mm
Blind thickness	0.2	mm
Pitch	12	mm
Blind tilting	15 - 30	°
Raise	1	mm

TABLE 1 Blind dimensions

The configuration of the two blinds has been modelled using both simplified and detailed approaches.

Simplified approach. The shading model was completely generated within the Berkeley Lab WINDOW software. The coating behaviour was assumed as Lambertian in order to use the material definition of WINDOW. In particular, the measured spectral data of the coating have been imported into WINDOW as shade materials. Table 2 shows the integrated reflectance values of the coating and the emissivity used as material for the blinds. The blind geometry has been precisely reproduced using the built-in functionality of WINDOW to generate custom horizontal venetian blinds; Fig. 5 shows the lamellas' definition within the *Shading Layer Library*.

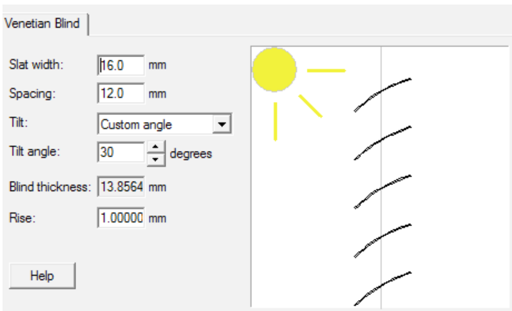

FIG. 5 Blinds geometry in WINDOW

Conductance	100 W/m k
Thickness	0.2 mm
Integrated values	
Solar Reflectance Front	0.901
Solar Reflectance Back	0.840
Visual Reflectance Front	0.959
Visual Reflectance Back	0.823
Emissivity Front	0.150
Emissivity Back	0.450

TABLE 2 Coating characterisation within WINDOW

Detailed approach. The shading modelling is performed using angular measured data and Radiance. The highly reflective coating has been characterised by means of measured angular reflectance values (BRDF) for Visible and Near Infrared wavelengths. The BRDFs were applied as material to the 3D geometry of the blinds within Radiance. The function genBSDF was then used to describe the geometry of the shade and its complex coating in the form of BSDF, with Klems resolution, for solar and visible spectrum. Additionally, a third BSDF for the infrared (IR) wavelength was created using the *plastic* material of Radiance and assuming as coefficient of reflection the complement to 1 of the emissivity front and back in Table 2. This last step was required in order to evaluate the hemispherical emissivity front and back and the infrared transmission of the system. Finally, an XML file that collects all the previous information was generated and imported into WINDOW.

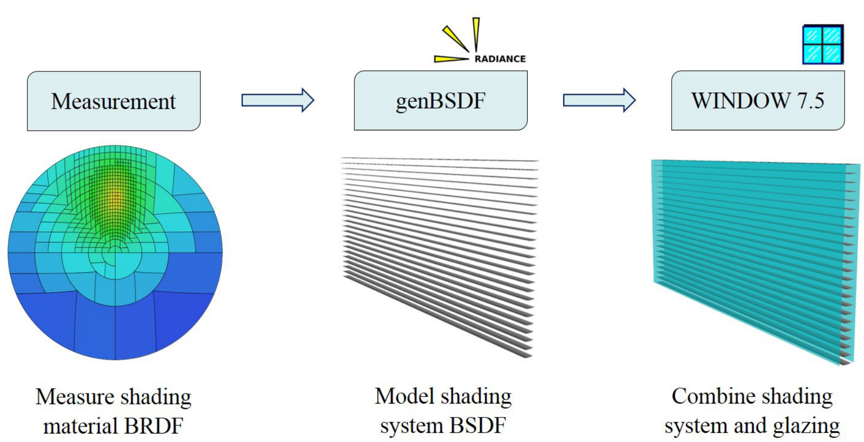

FIG. 6 Workflow of the detailed modelling procedure of the shading system

The shade models were then coupled with the glass layers within WINDOW in order to compose the complete system (Fig. 6). The fenestration consists of a triple-pane insulating glazing (8-29-6-16-8.8). Glass layers 1 and 2 are monolithic float glass, while layer 3 is laminated float glass; their sizes and thermal properties are listed in Table 3. On faces 3 and 5, a low-emissivity coating is placed. The cavities are filled with a gas mixture containing 90% argon and 10% air. The thermal and optical characteristics of the glazing system are: U-value 0.72 W/m2 K, SHGC 0.527 and visible transmission 0.6. The shading system is located in the first cavity, 29 mm. No window frame is considered.

PROPERTY	GLASS1	GLASS2	GLASS3
Thickness (mm)	8.0	6.0	8.8
Solar transmittance	0.797	0.618	0.573
Solar reflectance front	0.074	0.247	0.245
Solar reflectance back	0.074	0.186	0.137
Visual transmittance	0.892	0.893	0.882
Visual reflectance front	0.082	0.044	0.043
Visual reflectance back	0.082	0.048	0.048
IR transmittance	0.000	0.000	0.000
Emissivity front	0.837	0.037	0.037
Emissivity back	0.837	0.837	0.837
Conductivity	1.000	1.000	0.757

TABLE 3 Thermal and optical properties of glazing panes

4.2 IMPACT AT FAÇADE LEVEL: SIMPLE PROCEDURE AGAINST ADVANCED CHARACTERISATION

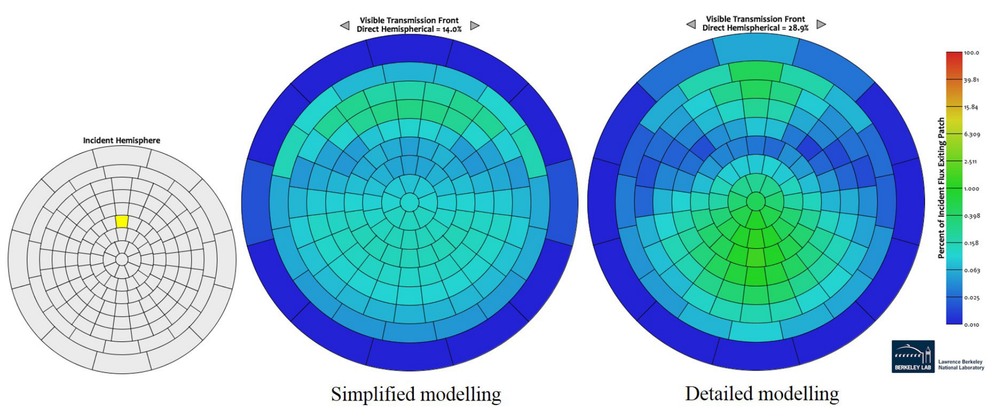

FIG. 7 BSDFs Visible Transmission Front for the fenestration system with blind titled at 15°. The graphs show the 145 outgoing values of visible transmission for an incident ray normal to the system and at 30° of elevation (yellow patch on the first left image).

A first comparison can be done by observing the differences between the angular visible transmission of the CFS in Fig. 7. In particular, the case with blinds tilted at 15° with an incident ray of azimuth angle 0° and elevation angle of 30° is shown. The difference between the models is evident; the detailed approach is able to reproduce the inter-reflections that occur between the blinds due to the high reflectivity of the coating. The angular transmission values are higher, green and yellow patches in the right graph of Fig. 7, compared to the simplified model, which underestimates the light transmission. In fact, the hemispherical front transmission values are very different: 35% for the detailed model against 17.6% for the simplified model. Similar behaviour has been found for other incident angles and blind configurations.

Another relevant consideration can be made, based on the angular Solar Heat Gain Coefficient (SHGC). Fig. 8 shows the SHGC values for 145 incident angles, for the cases analysed. Looking at the polar graphs, it can be observed that in general the detailed model has greater values of SHGC in the upper part of the hemisphere compared to the simple model. Therefore, the simple model will underestimate the solar gain in the thermal simulation.

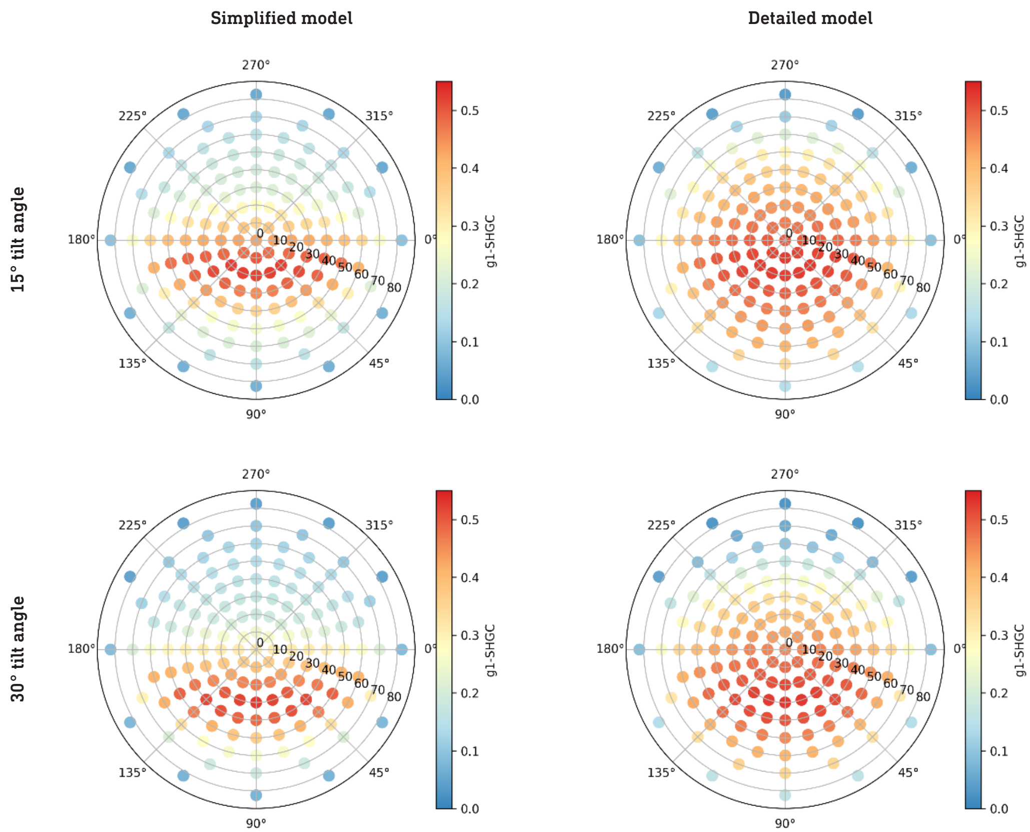

FIG. 8 Angular dependent SHGC

4.3 IMPACT ON REFERENCE ROOM: SIMPLE PROCEDURE AGAINST ADVANCED CHARACTERISATION

The previous paragraph has reported the differences between the simplified and detailed approach at the façade level. In this part, the two modelling approaches for CFS have been evaluated at a reference room level, using TRNSYS18 with the new CFS module based on ISO 15099 for the energy part, and the Daylighting Coefficient Method of Radiance for the daylighting analysis. The model used is a single zone of dimensions 3.3 m x 8 m x 2.7 m, located in Bolzano (46.467° N and 11.33° E), Italy. The zone consists of a south facing external façade with a window-to-wall ratio (WWR) of 50% (Fig. 9). In order to underline the effect of the façade on the energy balance, all the surfaces are assumed adiabatic except for the south-façade, and internal gains are not considered.

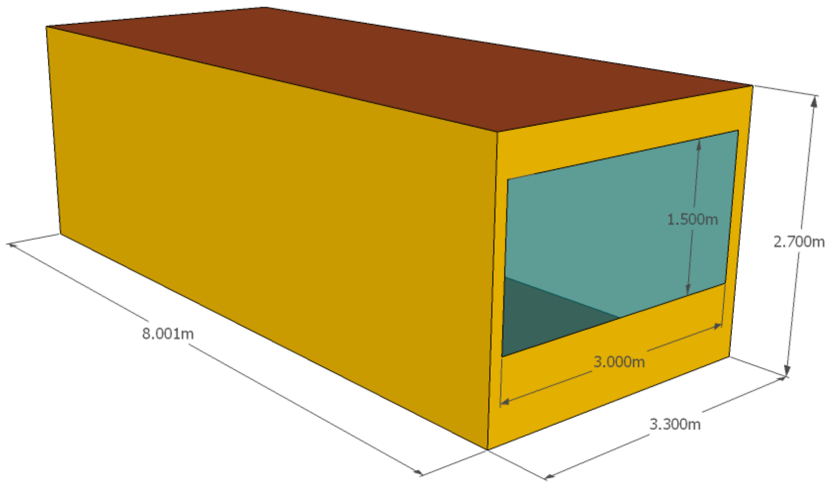

FIG. 9 3D model and main dimensions of the zone

The opaque element transmittance and reflectance are reported in Table 4. The set point for cooling is 20 °C, while for heating it is 26 °C. The heating and cooling system has unlimited power and is always on. Infiltration is always set to 0.40 ACH. The daylight availability is calculated over a grid located at 0.8 m from the floor and with a resolution of 0.5x0.5 m.

SURFACE	U [W/M^2 K]	REFLECTANCE
Wall	0.51	0.50
Roof/Ceiling	0.32	0.85
Floor	0.39	0.25
Ground	-	0.20

TABLE 4 Thermal and optical characteristics of the opaque elements

Results are reported for the two cases analysed, blinds always deployed at 15° and at 30° tilt angle. The comparison between simplified and detailed modelling is done on the annual ideal energy load and annual daylight distribution.

A / 15° tilt angle		
	Heating [kWh/m2y]	Cooling [kWh/m2y]
Simplified	13.1	10.1
Detailed	7.1	21.1
Difference	-46%	108%

B / 30° tilt angle		
	Heating [kWh/m2y]	Cooling [kWh/m2y]
Simplified	17.1	7.4
Detailed	8.6	12.6
Difference	-50%	69%

TABLE 5 Ideal heating and cooling demand for shadings deployed at 15° (A) and 30° (B)

Table 5 shows ideal heating and cooling load for the two blind tilt angles. The differences between simplified and detailed are relevant in both cases, especially for the cooling demand with blinds at 15°, where the difference rises to 108% (Table 5A). The detailed model considers the effective reflection of the material blind and then it accounts for a higher solar gain as also shown in the images in Fig. 8. Both in summer and winter seasons, the solar gains through the detailed model are higher than the simplified model. In fact, the heating demand is overestimated by 46%. Similar trends are found for the lamellas at 30°. The cooling difference is reduced to 70% since the more closed position of the blinds reflect more energy when the sun is around the solstice period.
The difference in heating load is slightly higher (50%) because the detailed model accounts for the inter-reflected direct radiation, which is more relevant for the 30° tilt angle case.

A / 15° tilt angle				B / 30° tilt angle			
	Simplified	Detailed	Difference		Simplified	Detailed	Difference
UDI-n	19.1	17.5	-8%	UDI-n	24.4	19	-22%
UDI-s	26.5	24.1	-9%	UDI-s	28.3	23.7	-16%
UDI-a	48.2	46.9	-3%	UDI-a	44.6	49.2	10%
UDI-x	6.2	11.5	85%	UDI-x	2.7	8.2	204%
DA_300	54.5	58.5	7%	DA_300	47.3	57.3	21%
sDA_300/50	58.3	62.5	7%	sDA_300/50	62.8	71.8	14%

TABLE 6 Daylighting indicators for shadings deployed at 15° (A) and 30° (B). Values are averaged over the sensor grid.

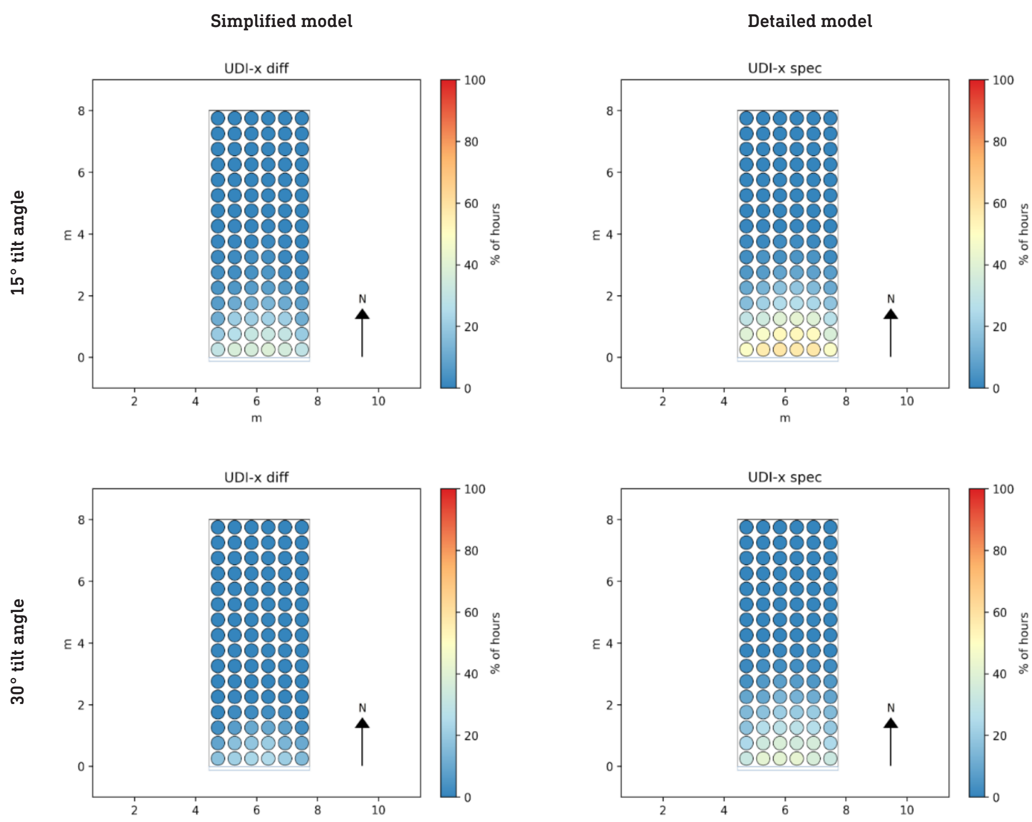

FIG. 10 UDI-exceed (Illuminance > 3000 lux) distribution over the sensors grid

Table 6 shows the average sensor grid values of selected annual daylighting indices for the two cases. The indicators used for the comparison are Useful Daylight Illuminance (UDI) (Mardaljevic & Nabil, 2005), Daylight Autonomy (DA) and spatial Daylight Autonomy (sDA) (Reinhart, Mardaljevic, & Rogers, 2006). For the latter two indices, the illuminance threshold was set to 300 lux. Regarding the daylighting results, the main differences were found for the case with 30° tilting. This is explained by the fact that the more the blinds are closed, the greater is the influence of the inter-reflection caused by the specularity of the blind coating. In particular, the simple model underestimates the percentage of hours in which the illuminance values exceed the 3000 lux (UDI-x) of the 204%. Additionally, in the case of 15° tilt, the greater difference is for the UDI-x, 85%. The main differences are related to the UDI-x, also because this index is primarily evaluated on the sensors close to the window (Fig. 10), and then close to influence of the shading system.

In general, the trend agrees with the expectation; the detailed model reduces the indices of illuminance below a threshold value (i.e. UDI-n and UDI-s, illuminance values below 100 lux, and between 100 and 300 lux respectively) from 8% to 22% for the cases with 15° tilt and 30° tilt respectively, while increasing the indicators of illuminance higher than a threshold (i.e. DA, sDA), from 7% to 21%. This result clearly shows that the detailed model allows for a major quantity of light entering the space.

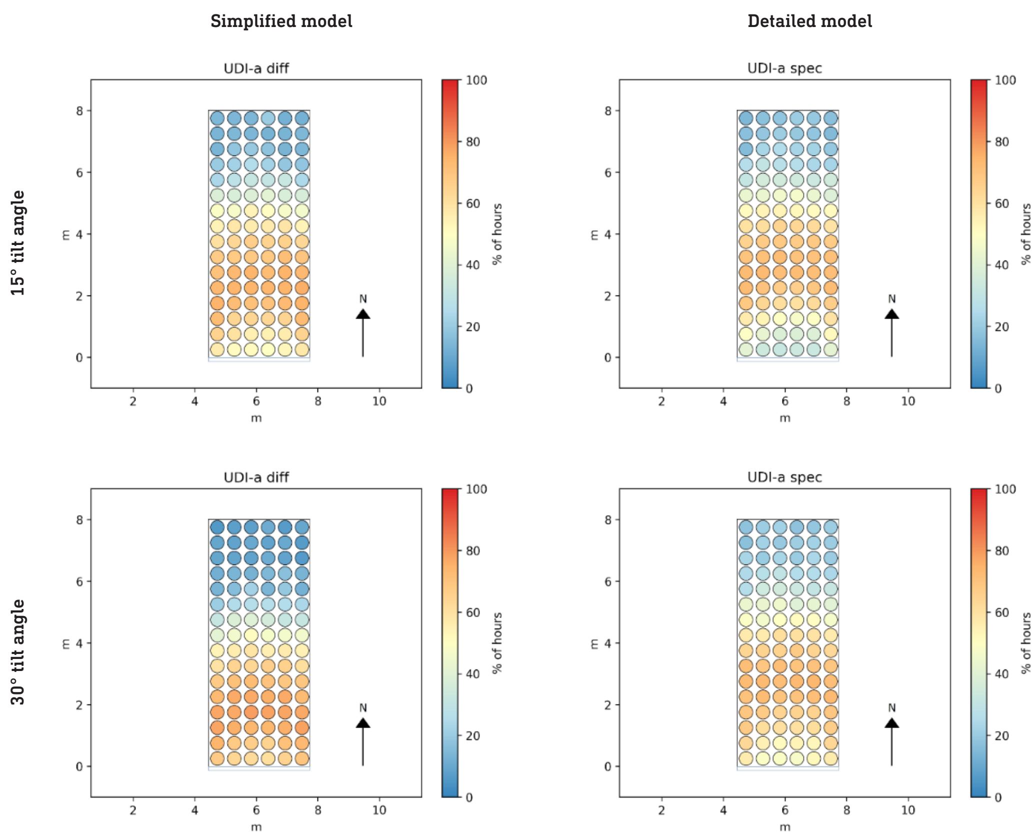

FIG. 11 UDI-autonomous (300 lux < Illuminance < 3000 lux) distribution over the sensors grid

Another important consideration concerns the UDI-a (i.e. illuminance level between 300 lux and 3000 lux). In both cases, the difference related to this index is small (-3% and 10%), but looking at the UDI-a distribution over the grid in Fig. 11, the distribution of the highest UDI-a values, for the detailed model, shifts almost one metre inside the room. This means that with the detailed model the light penetrates deeper into the room, and that the simple model would not be able to highlight this effect.

5 CONCLUSIONS

This article has reviewed several challenges and opportunities of modelling the performance of CFS in building simulation software. First, the unique simulation requirements were identified in terms of physical phenomena and the intended purpose of the simulation task. Then, a detailed overview of CFS models in state-of-the-art BPS tools was given, complemented by a description of bi-directional scattering distribution functions, and how such input data can be obtained. The second part of the article has demonstrated these concepts in a practical case study with a highly-reflective lamella system. The main take-home message of the case study relates to the complexity level of the simulation models, showing that this should always be carefully chosen with respect to the characteristics of fenestration system and the type of questions the simulation study should address.

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