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TOWARDS AN ISO/CIE STANDARD FOR BSDF CHARACTERIZATION OF SHADING AND DAYLIGHTING SYSTEMS

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Abstract

Shading and daylighting systems such as textiles, louvres, and prismatic glazings are used to modulate incident solar radiation. The scattering properties of these “complex fenestration systems” (CFS) determine the temporally-variant, spatial distribution of daylight and solar radiation and thus affect the energy, global warming potential, comfort, health, and qualitative performance of buildings and the urban environment. Angle-dependent, solar-optical properties of CFS (i.e., bidirectional scattering distribution function (BSDF) data), however, are often unavailable or inaccurate, hindering simulated evaluations of environmental performance. New general methods for characterizing BSDF properties have been developed and extensively validated. This article describes the ISO/CIE 25176 initiative (launched in July 2024) that aims to standardize these methods for any arbitrary CFS. Open questions such as the limits of applicability are discussed. Standardization will have immediate implications on building performance analyses, e.g., the recent adoption of ISO/CIE 10916 for lighting energy simulations now requires use of BSDF data.

Keywords: Bidirectional scattering distribution function (BSDF), complex fenestration systems (CFS), characterization, standardization, daylight simulation

1 Introduction and Motivation

Shading or daylighting devices are mentioned in several standards or regulations and must be evaluated by standardized methods. They are of growing importance in the context of greater overheating risks in buildings and for maintaining visual comfort. For the most part, however, there is nothing specified regarding how the devices can or should be represented. BSDFs offer an efficient opportunity for this. The revised standard ISO/CIE 10916:2024 (ISO/CIE, 2024a) adds the three-phase matrix calculation method (Ward et al., 2011) in its new Annex B and thus explicitly requires BSDF data for daylight calculations. Certification schemes (e.g. LEED, BREEAM, WELL, DGNB) and guidelines (e.g. German Technical Rule for Workplaces, European standard EN 17037, ASHRAE) exist in various application areas that relate to daylighting or solar heat gains. The three-phase method and associated BSDFs often underlie calculation of the metrics associated with these schemes.

As such, BSDFs have found their way into software tools for climate-based daylight modelling and energy simulation (e.g., Radiance (see example in Figure 1), ClimateStudio, Ladybug/Honeybee or DIALux for daylight simulations and EnergyPlus, ESP-R, Fener, IDA ICE or TRNSYS for building performance simulations, to name just a few). Expert tools such as WINDOW use single layer BSDFs as input to produce BSDF representations of fenestration comprised of multiple transparent and scattering layers. These tools and by association BSDF data are used by established lighting design offices and energy consultants, despite no normative background on how to generate and apply BSDFs.

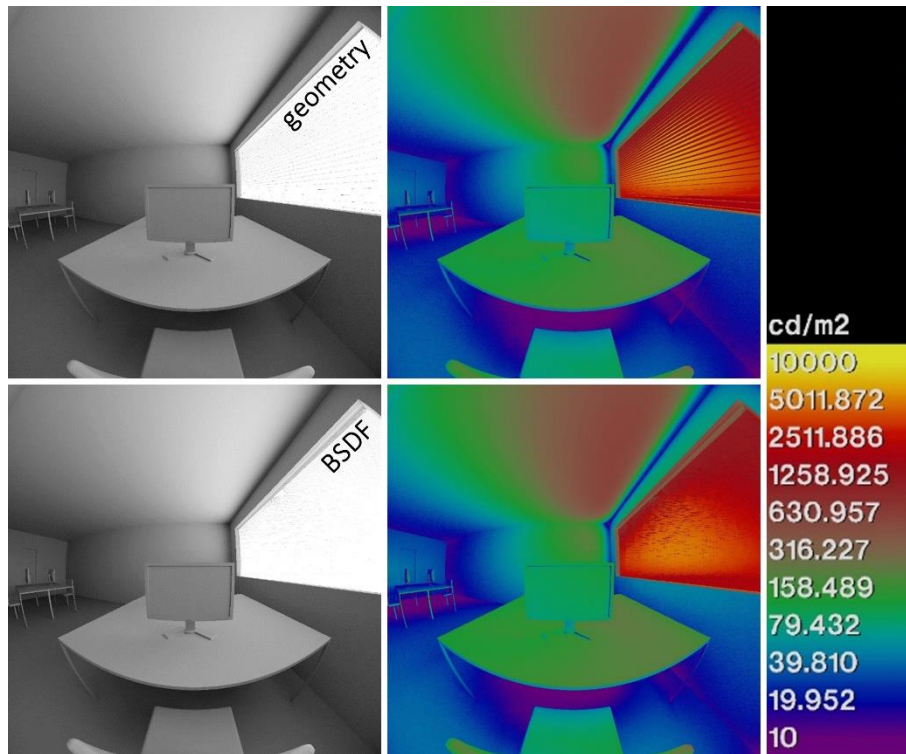


Figure 1 – Daylight simulation in Radiance with example CFS (venetian blinds) modelled as geometry (top) and represented through their BSDF (bottom). The light distribution in the interior is ideally reproduced by the BSDF though differences can be seen in the luminance pattern at the window. These differences can be significantly larger if the reflectance properties of the slat material are inadequately characterized.

For transparent glazing in windows, standardized methods are well established to characterize the angle-dependent, solar-optical properties (visible and solar transmittance, absorptance, reflectance). Standardized methods do not exist however for “optically complex” or light scattering, shading and daylighting systems. This in turn makes objective evaluation of energy performance, solar distribution, daylighting, comfort, and other building performance qualities almost impossible. Simplified methods for characterizing complex fenestration systems (CFS) have been developed based on normal-normal, normal-hemispherical, and diffuse-hemispherical transmittance and reflectance measurements. These methods have found their way into European standards (EN 14500/14501) and international standards (ISO 52022-1 and ISO 52022-3), but can contribute to significant errors in the assessment of daylighting, indoor environmental quality (visual comfort) and solar gains-related building energy performance.

For example, the latest revision to the analytical models in the standards series EN 14500/14501 introduces the concept of the “cut-off angle” for glare control classification of solar-shading devices (e.g., fabrics). The cut-off angle is the minimum angle of incidence at which $\tau_{\text{dir-dir}}$ is below 0,005. Even in combination with the values for $\tau_{\text{n-n}}$ and $\tau_{\text{n-dif}}$, which define the glare control classes, this can still lead to omitting scattered sunlight that has the potential to cause glare or thermal discomfort. As a note on the cut-off angle, EN 14500 even states: “*BSDF measurements might be used as input for more complex situations*”.

In a comprehensive overview, De Michele and others describe why building performance simulations now often rely on BSDFs for optical modelling and no longer use normative methods (De Michele et al., 2018). In particular, they point out that while the standard approach for considering the characteristics of CFSs is the layer-by-layer approach and follows the ISO 15099 method, there are numerous simplifying assumptions that limit generalization. For example, the normative methods only apply to selected systems (e.g., flat or curved blinds) and have strict limitations with regard to materials (only diffuse, no reflective / scattering / transmitting materials).

Bueno et al. also point out that the assessment of the performance of innovative shading systems is partly outside the scope of the ISO 15099 analytical model and therefore requires other approaches. In

order to meet the challenge of modelling the angle-dependent properties of CFSs in the best possible way, they have used directional solar heat gain coefficients in their Fener software and linked these with BSDFs for calculation of light and solar radiation (Bueno et al., 2017).

As an example of significant errors, in a study evaluating analytical models for fabrics (Wang et al., 2023), the mean average error (MAE) between model and measured direct-hemispherical transmittance was 15,5 % and 36,3 % (without cut-off angle) and 10,3 % and 20,2 % (with cut-off angle) for incident θ angles of 150° to 120° and 120° to 90°, respectively (typical sun angles in non-equatorial regions). For direct-conical(5°) transmittance, the MAE was 86,5 % and 1450 % (without cut-off angle) and 31,5 % and 166 % (with cut-off angle) for the same range of θ angles, respectively. The analytical models assume isotropism so poor agreement between simulated and field measured data were attributed in part to anisotropic characteristics.

2 Background

The bidirectional scattering distribution function (BSDF) describes how radiation incident from one direction is reflected off and transmitted through a surface to another direction. If a surface is viewed from direction (θ_s, ϕ_s) , the observed luminance L_s is calculated according to Equation (1) as:

$$L_s(\theta_s, \phi_s) = \int_0^{2\pi} \int_0^\pi L_i(\theta_i, \phi_i) BSDF(\theta_s, \phi_s; \theta_i, \phi_i) |\cos \theta_i| \sin \theta_i d\theta_i d\phi_i \quad (1)$$

where $L_s(\theta_s, \phi_s)$ is the luminance in the scattered direction with polar and azimuthal angles (θ_s, ϕ_s) , and $L_i(\theta_i, \phi_i)$ is the luminance in incident direction (θ_i, ϕ_i) , respectively. Figure 2 shows the geometric relationship between the incident and scattered directions in the case of transmission.

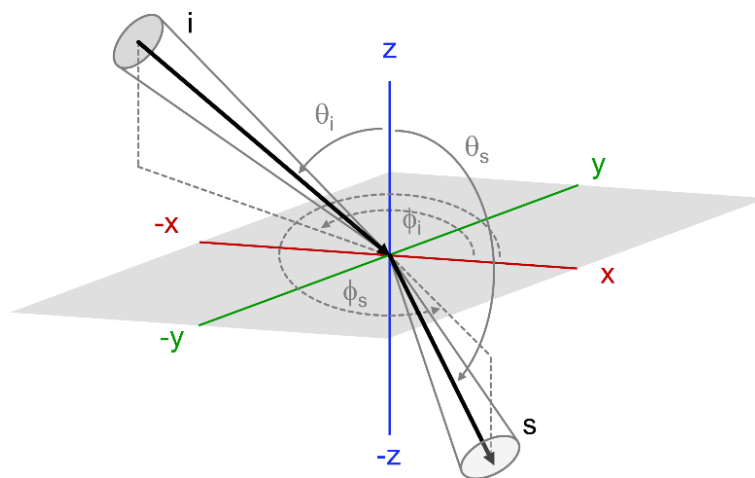


Figure 2 – Incident (i) and scattered (s) directions

In order to generate *general* BSDFs representing any arbitrary daylighting or shading system, point-based BSDF measurement data must be converted into a discretised model covering both hemispheres of incident and exiting directions. One such scheme was introduced in 1994 (Klems, 1994a and 1994b) to provide BSDF coefficients for approximately equal projected solid angles for each hemisphere. Figure 3 shows the distribution of the direct-hemispherical transmission of a venetian blind system for light incident from an altitude of 40 degrees discretized in so-called Klems patches.

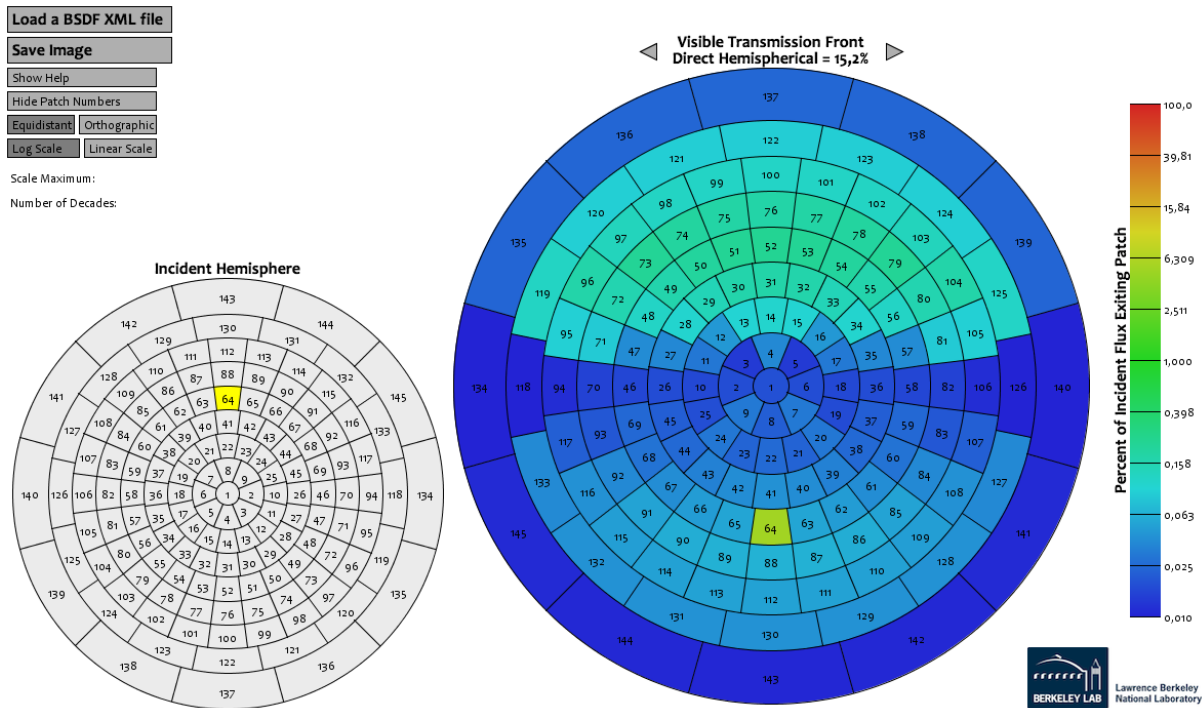


Figure 3 – Visualisation of BSRF for example CFS (venetian blinds) in Klems discretization for light incident from an altitude of 40 degrees.

Numerous studies have validated existing workflows that allow the generation of BSRF data (Geisler-Moroder et al., 2024). Within the collaborative project SHC Task 61/EBC Annex 77 “Integrated Solutions for Daylighting and Electric Lighting” from the International Energy Agency (IEA), a group of international experts summarized the state of the art of the proposed general method in a white paper entitled “BSRF generation procedures for daylighting systems” (Geisler-Moroder, 2021a). A review of implemented approaches at various institutes was additionally documented in a technical report (Geisler-Moroder, 2021b). The contents of both reports are the main starting point for the standardization work. Analytical models can be adequate for some classes of systems. However, general derivation of analytical models from measured BSRF data is not straightforward. More research is therefore needed before advancing them as standards.

There are also activities in a similar direction in other application areas. Particularly in the field of metrology, efforts are being made to characterise scattering properties of materials and to standardise the underlying measurements and procedures. Applications include the automotive industry, healthcare sector, glass manufacturers, and video game and virtual reality developers. These methods cannot be applied directly to shading or daylighting systems on a one-to-one basis, but the basic considerations are similar, and it may be possible to borrow some concepts. Here we refer in particular to the activities in the series of joint research projects “xD Reflect” (xD Reflect, 2025), “BiRD” (BiRD, 2025), “BxDiff” (BxDiff, 2025) and “xDDiff” (xDDiff, 2025), from which information is provided for standardisation work in CIE TC 2-85 “Recommendation on the geometrical parameters for the measurement of the Bidirectional Reflectance Distribution Function (BRDF)” (CIE, 2025).

3 Proposed contents of the new standard

To address the lack of standardisation of BSRF data, the International Organization for Standardization (ISO) and the International Commission on Illumination (CIE) launched the project ISO/CIE 25176 “Light and lighting – Daylight in buildings – BSRF data generation for complex fenestration systems” in 2024 (ISO/CIE, 2024b) as a collaborative effort between ISO/TC 274/JWG 1 and CIE Division 3/JTC 06.

The defined scope of the project is to compose a standard that “*specifies procedures for:*

- (i) *characterizing angle-dependent, optical properties (transmittance, reflectance, absorptance) of glazing and shading materials and systems, i.e., “complex fenestration systems” (CFS) and then*
- (ii) *generating tabulated bidirectional scattering distribution function (BSDF) data sets for use as input to simulation tools.”*

The objective of the standard is to establish “*generally applicable methods for BSDF characterization of CFS for evaluation of performance criteria based on spatially resolved (luminance, solar patch) and/or integral radiation quantities (illuminance, solar irradiance) and thus on definitions and specifications for generating tabulated BSDF data. The subsequent derivation of analytical models in order to characterize some types of CFS with a large number of similar variations is not included in this document. Characterization of CFS as a function of wavelength (spectrally resolved) or position on a non-homogeneous surface is also not included in this scope.*”

The overarching goal of the standard is to provide certainty and support for architects, designers, consultants and manufacturers who need BSDF data in order to perform high-quality daylighting simulations and solar energy evaluations for their building projects and products. The result should clearly specify methods to create BSDF data that are suitable as input for daylighting and energy simulation tools as well as for normative methods such as ISO/CIE 10916.

In the normative part, the standard will describe the necessary basics and specify methods for creating the data for microscopic and macroscopic CFS. This differentiation follows the recommendation from the IEA white paper (Geisler-Moroder, 2021a): A *microscopic* system describes “*a daylight system that can be directly measured with a gonio-photometer, i.e., that has a structure where the scattering properties can be characterized correctly from a representative area of the system (e.g., roller shade fabric, microstructured prismatic film)*”. A *macroscopic* system is defined as “*a daylighting or shading system that cannot be directly measured with currently available goniophotometers (i.e., cannot measure a representative area of the system (e.g., venetian blinds, honeycomb blinds, fabrics with arbitrary patterns or surfaces with irregular perforations))*”. These systems’ spatial extent is too large for typical far-field measurements with a spatially integrating sensor and/or the illuminated area. For microscopic systems, the standard will refer to existing standardised methods for measuring scattering properties for reflection and transmission of surfaces, such as ASTM E2387-19 (ASTM, 2019) or, as mentioned above, the new work from CIE TC 2-85. For macroscopic systems, the use of virtual goniophotometers is recommended, i.e., simulation-based data acquisition. Geometric models and material specifications are assumed as the basis, whereby the latter can be either based on fundamental physics models (e.g. index of refraction) or based on real measurements (i.e., following the specification for microscopic systems).

The core content of the planned standard is therefore not so much the actual, single BSDF measurement instructions (for which reference is made to other standards), but rather the entire process of data collection, conversion into a suitable discretisation, provision in an appropriate file format, as well as optional validation and embedding of proxy geometry. The standard is thus focused on the use case for shading and daylighting systems and the associated requirements in normative procedures (ISO/CIE 10916) and daylighting and building simulation tools.

One critical aspect of the workflow is its dependence on the scattering distribution of the material. If the transmitted and/or reflected distribution in the exiting direction is uniform, the measurement for prescribed angles of incidence and exiting directions is straightforward. If the exiting distribution is peaky (e.g., specular or near-specular transmission and/or reflection and/or redirection), additional detailed measurements will be required. Here, the goniophotometer’s instrument signature is critical to adequately capturing local peaks and the workflow from measured data to interpolant to BSDF representation is critical as well. The standard will aim to define the workflow for such systems for applications that involve spatially resolved quantities and to distinguish these data from data developed solely for computation of integral quantities.

In the normative part, for example, the procedure is to be defined for which directions of incidence goniophotometric measurements must be taken depending on the sample symmetry. An XML-based data format is also to be described. In informative annexes, various angular bases for BSDF discretization, and a method for interpolation of goniophotometer measurements are described. Further, the optional validation procedure for the direct-hemispherical transmission values is explained, and optional inclusion of proxy geometry of the CFS in BSDF data files are specified. Finally, two example procedures for fabric shades and for venetian blinds are outlined.

4 Discussion and conclusion

There are open questions regarding the BSDF characterization of daylighting systems and their application in daylighting simulation tools. With the general method for generating BSDF data, the characterization will be covered with some exceptions. Special cases such as spectrally resolved BSDF data or the creation of BSDFs for spatially non-homogeneous samples are not covered. The two examples of fabrics and venetian blinds provided in the standard show the clear intention that the new standard ISO/CIE 25176 should be applicable to common and frequently used shading and daylighting systems. The application of BSDFs and recommendations as to which types of BSDFs should be used for which combinations of methods and systems are not in the scope of the standard.

Novel methods for BSDF measurement and data generation are being developed at various institutes. The University RPTU Kaiserslautern and Fraunhofer CSP (Centre for Silicon Photovoltaics) have developed a near-field measurement method for faster detection of BSDFs of laterally extended structures using angular selectors (VDI, 2024). Researchers at the University of Innsbruck developed a method for fast and cost-effective measurement of BTDFs using 145 illuminance sensors arranged in a hemisphere that are sampled simultaneously (MEZeroE, 2025). Both methods are designed to efficiently generate low-resolution BSDF data according to Klems discretization.

For the characterisation of innovative systems, e.g., highly angular-selective or redirecting systems, low resolution BSDF data are often not suitable, especially when it comes to detailed consideration of sunlight or luminance-based evaluations such as glare. This also poses a major challenge for the measurement, where the instrument signature (the minimum resolvable feature in the measurement setup) often does not allow such measurements at all. To solve this, approaches with higher resolution BSDFs coupled with additional algorithmic solutions such as peak extraction from BSDF data as proposed in (Geisler-Moroder et al., 2021c) will be needed.

The standard is currently in the development stage and will be available as a committee draft at the time of the conference. This means that there is an initial draft that is waiting to be reviewed and critically commented on by international experts. We invite all experts in the field of BSDF data generation and interested parties to participate and contribute via their respective national committee of ISO TC 274 or through their CIE National Committee. The main objective of the standard is to complete a previously missing part of the standardization (for ISO/CIE 10916) and to create a normative basis for generating BSDF data for daylight simulations. This should help architects, planners and manufacturers to carry out assessments and simulations with shading and daylighting systems even more reliably.

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