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Light and lighting — Daylight in buildings — BSDF data generation for complex fenestration systems

Lumière et éclairage — La lumière du jour dans les bâtiments — Génération de données BSDF pour un système de fenêtrage complexe

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Foreword

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This document was prepared by Technical Committee ISO/TC 274, *Light and Lighting*, in collaboration with the International Commission on Illumination (CIE), JTC 06, *Energy Performance of Lighting in Buildings*.

Any feedback or questions on this document should be directed to the user’s national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

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Introduction

Analysis of daylight and electric lighting involves determining the intensity and distribution of light over a wide range of scales, from small when conducting research on new materials to large when evaluating the health effects of diminished daylight in high density urban areas. The temporal scale varies from a single peak or design day condition to annual analyses at a e.g. five-minute interval in the case of integrated control systems designed to increase energy efficiency, comfort, environmental quality, and utility grid resiliency. Innovative ray-tracing methods have been developed to accommodate this broad range in applications, many now capable of delivering a high degree of accuracy without sacrificing computational speed, but whether it be conventional or advanced algorithms, all such simulations are based on angularly resolved solar-optical data to describe the scattering properties of the surfaces and systems that the rays of light encounter (e.g. glass, frits, louvers, fabrics, etc.). The behaviour of how incident radiation is reflected or transmitted is described by the bidirectional scattering distribution function (BSDF). Tabulated BSDF data are analogous to the candlepower or luminous intensity distribution data that accompanies every light fixture. Use of such data can be recommended or compulsory, for example, the “Comprehensive Hourly Calculation” method in ISO/CIE 10916:2024 [1], Annex B is based on BSDF data. Similarly, matrix-based daylight simulations such as the 3-phase method or the 5-phase method require BSDF data [2]. A standardized, publicly available BSDF library is similar to the International Glazing Database where a library entry can be simply substituted for another and an annual analysis can be re-run in a matter of seconds to re-evaluate performance.

To date, BSDF data have been supplied by physics-based models (e.g. index of refraction for transparent glass) and analytical models based on limited measurements. For many materials and systems, simplifying assumptions (e.g. Lambertian properties assumed for a semi-specular material) can result in significant errors in simulated performance. There are published BSDF data currently available from reputable institutions, but without in-depth expertise, it is very difficult for end users to determine whether the data with its underlying assumptions are sufficient for the intended application.

To address these concerns, a general, data driven, empirically based method has been developed to characterize the light (applicable to visible, solar, full spectrum wavelengths) scattering properties of any arbitrary material or system. It is this BSDF generation method that is described in this document. The instrumentation, metrology, and algorithms for converting the measured data to a usable format described herein have been developed and validated over the course of several decades by researchers worldwide [3]. The resultant BSDF data can be used to compute key performance indices/ metrics that require a low to very high degree of spatial resolution for the input data (e.g., performance metrics that require sunlight intensity over a large-area patch on the workplane or on a small area of the body such as the head or foot). It is this key aspect – spatial resolution – that defines the adequacy of the BSDF data for a given performance metric.

The importance of using a characterization method that adequately captures the scattering properties of the material cannot be understated. There are serious concerns that can be addressed up front at the start of the design phase rather than at the end of the project when it is much more difficult to remedy the problem in the built environment. For materials that allow full or partial specular transmission or reflection, for example, additional highly resolved angular measurements are needed to evaluate veiling glare, discomfort glare, lighting quality with sunlight redirection, etc. For materials that exhibit diffuse scattering properties, such detailed measurements may not be as important. For other fields which are also reliant on these solar-optical data to assess designs or develop new emerging technologies, such as heating and cooling in buildings and the urban environment (e.g., thermal comfort with evolving spatially resolved models), horticulture, agriculture, etc., the degree of concern is as yet unknown.

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Light and lighting — Daylight in buildings — BSDF data generation for complex fenestration systems

1 Scope

This document applies to the broad range of materials and systems, e.g. fabric shades, venetian blinds, prismatic glass, etc., that are used on windows and skylights to control daylight, sunlight, glare, privacy, and view to the outdoors. It specifies procedures for producing comprehensive angle-dependent, solar-optical scattering data that can then be used to compute a wide range of performance metrics.

This document specifies procedures for:

a) characterizing angle-dependent, optical properties (transmittance, reflectance, absorptance) of glazing and shading materials and systems, i.e. "complex fenestration systems" (CFS) and then

b) generating tabulated bidirectional scattering distribution function (BSDF) data sets for use as input to simulation tools or standardized calculation methods such as the comprehensive hourly calculation method defined in ISO/CIE 10916:2024 [1].

This document establishes 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 methods apply for the full solar spectral range from 280 nm to 4000 nm including ultraviolet, visible and infrared regions.

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 the scope of this document.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ASTM E2387 - 19, *Standard Practice for Geometric Optical Scatter Measurements*

3 Terms, definitions, symbols, indices and abbreviated terms

For the purposes of this document, the following terms and definitionsapply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

CIE maintains a terminology database for use in standardization at the following address:

— e-ILV: available at https://cie.co.at/e-ilv

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3.1
bidirectional reflectance distribution function
BRDF
sample BSDF measured in a reflective geometry

[SOURCE: ASTM E2387 - 19, 3.2.5]

3.2
bidirectional scattering distribution function
BSDF
sample radiance L_e divided by the sample irradiance E_e for a uniformly-illuminated and uniform sample:

$$BSDF = \frac{L_e}{E_e}\left[sr^{-1}\right] \quad (1)$$

Note 1 to entry: If a surface is viewed from direction (θ_s, ϕ_s), the observed luminance L_s is calculated as:

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

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 1 shows the geometric relationship between the incident and scattered directions.

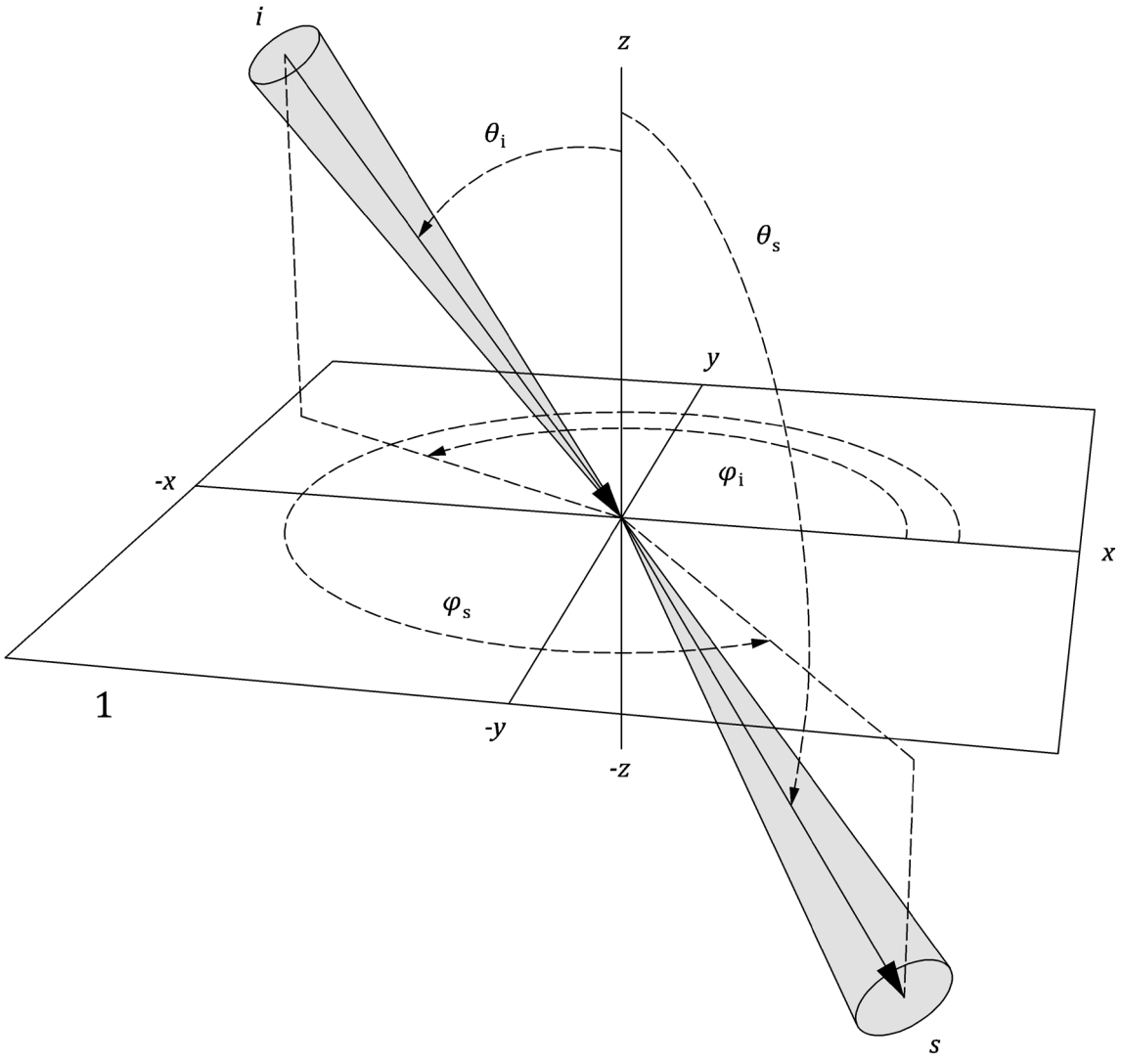


Figure 1 — Geometric relationship between incident and scattered directions

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Note 2 to entry: The *BSDF* (3.2) consists of two parts - the *bidirectional reflectance distribution function* (3.1) and the *BTDF* (3.3).

[SOURCE: ASTM E2387 - 19, 3.2.6, modified: Notes to entry added.]

3.3
bidirectional transmittance distribution function
BTDF
sample BSDF measured in a transmissive geometry

[SOURCE: ASTM E2387 - 19, 3.2.7]

3.4
BSDF instrument signature
mean scatter level detected when there is no sample scatter present expressed as BSDF

[SOURCE: ASTM E2387 - 19, 3.2.8]

3.5
differential scattering function
DSF
fraction of incident light scattered per unit solid angle, given by:

$$DSF = BSDF\cos(\theta_s) \tag{3}$$

[SOURCE: ASTM E2387 - 19, 3.2.10; modified: Alternative representation via limit value removed from formula.]

3.6
DSF instrument signature
mean scatter level detected when there is no sample scatter present expressed as a *DSF* (3.5)

[SOURCE: ASTM E2387 - 19, 3.2.13]

3.7
IEA21 angular basis
BSDF discretization using *Tregenza resolution* (3.13) for the incident hemisphere and an equidistant angular subdivision for the exiting hemisphere

3.8
Klems angular basis
BSDF discretization using *Klems resolution* (3.9) for incident and exiting hemispheres

3.9
Klems resolution
discretization of the hemisphere into 145 areas with approximately equal projected solid angles

3.10
macroscopic system
daylighting or shading system whose scattering properties cannot be directly measured with currently available goniophotometers (i.e. the structure or patterns that are a representative area of the system)

EXAMPLE Venetian blinds, honeycomb blinds, fabrics with arbitrary patterns or surfaces with irregular perforations.

3.11
microscopic system
daylighting or shading system that can be directly measured with a goniophotometer, i.e. that has a structure so that the sample aperture covers a representative area of the CFS

EXAMPLE Roller shade fabric, microstructured prismatic film.

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3.12
Shirley-Chiu / Tensor tree angular basis
BSDF discretization using a discretization of the hemisphere into areas with equal projected solid angles for the incident and the exiting hemispheres

3.13
Tregenza resolution
discretization of the hemisphere into 145 areas with approximately equal solid angles

4 Symbols, indices and abbreviated terms

4.1 Symbols

	Quantity	Unit
ϕ	azimuthal angle	° (degree)
θ	polar angle	° (degree)
E_e	irradiance	$W \cdot m^{-2}$
L	luminance	$cd \cdot m^{-2}$
L_e	radiance	$W \cdot sr^{-1} \cdot m^{-2}$
ρ	reflectance	-
$\rho_{dir\text{-}h}$	direct-hemispherical reflectance	-
τ	transmittance	-
$\tau_{dif\text{-}h}$	diffuse-hemispherical transmittance	-
$\tau_{dir\text{-}h}$	direct-hemispherical transmittance	-
$\tau_{n\text{-}h}$	normal-hemispherical transmittance	-

4.2 Indices and abbreviated terms

CAD	computer-aided design	ref	reference
CFS	complex fenestration system	RBF	radial basis function
FWHM	full width half maximum	s	scattered (outgoing)
i	incident (incoming)	SIR	scattering interpolant representation
k	patch index	XML	Extensible Markup Language
MGF	Materials and Geometry Format		

5 BSDF data resolution

Tabulated BSDF bases are specified via a discrete set of values for a defined number and set of incoming and outgoing, scattered directions (θ_s, ϕ_s; θ_i, ϕ_i). The resolution of measured and tabulated BSDF data shall match the optical properties of the represented CFS.

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