International Standard

ISO 9050

Glass in building — Determination of luminous and solar characteristics of glazing

Verre dans la construction — Détermination des caractéristiques lumineuses et solaires des vitrages

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Contents

Foreword

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The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular, the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation of the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT), see www.iso.org/iso/foreword.html.

This document was prepared by Technical Committee ISO/TC 160, *Glass in building*.

This third edition cancels and replaces the second edition (ISO 9050:2003[16]), which has been technically revised.

The main changes are as follows:

— changes to the calculation of the internal heat transfer coefficient;

— clarification provided that UV transmittance is determined only for the total range and not split into UVA and UVB;

— modification to normalized relative spectral distribution of global solar radiation based on 10 nm wavelength intervals;

— a procedure is provided for the calculation of the spectral properties of laminated glass;

— guidance is given on how to determine the spectral characteristics of screen printed glass;

— introduction of a matrix method for non-scattering incoherent optical systems, including multiple layers;

— modifications to the formulae to permit calculation and declaration of the luminous and solar properties of BIPV glazing;

— examples of calculation of colour rendering index have been given.

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.

Introduction

While this document presents the formulae for the exact calculations of the spectral characteristics of glazing, it does not consider the uncertainty of the measurements necessary to determine the spectral parameters that are used in the calculations. It should be noted that, for simple glazing systems where few measurements are required, the uncertainty of the results will be satisfactory if correct measurements procedures have been followed. When the glazing systems become complex and a large number of measurements is required to determine the spectral parameters, the uncertainty is cumulative with the number of measurements and should be considered in the final results.

In this document, the term “interface” is considered a surface characterized by its transmission and reflections of light intensities. That is, the interaction with light is incoherent, all phase information being lost. In the case of thin films (not described in this document), interfaces are characterized by transmission and reflections of light amplitudes, i.e. the interaction with light is coherent and phase information is available. Finally, for clarity, a coated interface can be described as having one or more thin films, but the entire stack of thin films is characterized by its resulting transmission and reflection of light intensities.

In Annex B, the procedure for the calculation of spectral characteristics of laminated glass makes specific reference to coated glass. The same procedure can be adopted for filmed glass (e.g. adhesive backed polymeric film applied to glass).

Glass in building — Determination of luminous and solar characteristics of glazing

1 Scope

This document specifies methods of determining the luminous and solar characteristics of glazing in buildings. These characteristics can serve as a basis for lighting, heating and cooling calculations of rooms and permit comparison between different types of glazing.

This document applies both to conventional glazing and to absorbing or reflecting solar-control glazing, used as vertical or horizontal glazed apertures. The appropriate formulae for single, double and triple glazing are given. A matrix method is provided as an alternative calculation method.

This document introduces a method to determine the luminous and solar properties of building-integrated photovoltaic (BIPV) glazing.

This document is accordingly applicable to all transparent materials except those which show significant transmission in the wavelength region 5 µm to 50 µm of ambient temperature radiation, such as certain plastic materials.

Materials with light-scattering properties for incident radiation are dealt with as conventional transparent materials subject to certain conditions (see 5.3).

Angular light and solar properties of glass in building are excluded from this document. However, research work in this area is summarised in References [1],[2] and [3].

Guidance on the measurement of luminous and spectral properties of glass can be found in Reference [4].

Vacuum insulating glass (VIG) is excluded from the scope of this document. For determination of the *g* value of VIG, refer to ISO 19916-1[5].

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.

ISO 10291, *Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Guarded hot plate method*

ISO 10292, *Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing*

ISO 10293, *Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Heat flow meter method*

ISO 20589, *Glass in building — Determination of the emissivity*

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

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

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

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

3.1
light transmittance
fraction of the incident light that is transmitted by the glass

3.2
light reflectance
fraction of the incident light that is reflected by the glass

3.3
total solar energy transmittance
fraction of the incident solar radiation that is transmitted by the glass, including secondary heat transfer following absorption

3.4
solar direct transmittance
fraction of incident solar radiation that is directly transmitted by the glass

3.5
solar direct reflectance
fraction of the incident solar radiation that is reflected by the glass

3.6
ultraviolet transmittance
fraction of the incident UV component of the solar radiation that is transmitted by the glass

3.7
colour rendering index in transmission
change in colour of an object as a result of the light being transmitted by the glass

3.8
shading coefficient
ratio of the total solar energy transmittance of the glass to the total solar energy transmittance of clear float glass

3.9
PV module
planar photovoltaic module
planar device designed to convert solar radiation into electricity by the photovoltaic (PV) effect

Note 1 to entry: The glazing configuration of a planar PV module may be, but is not restricted to, a coated or uncoated pane of glass, a coated polymer film, a glass-polymer laminate or a glass-polymer-glass laminate. For the sake of brevity, the term planar PV module is understood to mean a planar PV module in Annex E.

3.10
building-integrated photovoltaic glazing
BIPV glazing
architectural glazing that incorporates a *planar photovoltaic (PV) module* (3.9) as one of its panes

Note 1 to entry: In this context, architectural glazing refers to glazed apertures in buildings.

3.11
optically homogeneous
attribute of glazing with optical properties, which, when determined using a spectrophotometer, are independent of the position selected for measurement

Note 1 to entry: Many thin-film *planar photovoltaic (PV) modules* (3.9) are examples of optically homogeneous glazing.

3.12
optically inhomogeneous
attribute of glazing with optical properties, which, when determined using a spectrophotometer, vary significantly (i.e. by an amount greater than measurement tolerances) on the position selected for measurement

Note 1 to entry: Typically, this refers to areas on a scale of cm^2 that have a visibly different appearance, e.g. crystalline photovoltaic (PV) cells surrounded by a transparent embedding material.

3.13
open circuit
OC
electrical state of a photovoltaic (PV) device in which the output electric current is zero

Note 1 to entry: Adapted from IEC TS 61836:2016, 3.4.57.

3.14
maximum power point
MPP
point on a PV device's current-voltage characteristic where the product of electric current and voltage yields the maximum electrical power under specified operating conditions

[SOURCE: IEC TS 61836:2016, 3.4.43.3]

3.15
standard test conditions
STC
reference values of in-plane irradiance $\left(G_{\text{I,ref}} = 1\,000\ \text{W}/\text{m}^2\right)$, photovoltaic cell junction temperature (25 °C), and a reference spectral irradiance distribution calculated for air mass = 1,5 to be used during the testing of any photovoltaic device

[SOURCE: IEC TS 61836:2016, 3.4.87]

3.16
conversion efficiency
ratio of electric power generated by a photovoltaic (PV) device per unit area to its incident irradiance

[SOURCE: IEC TS 61836:2016, 3.1.17]

3.17
interface
surface characterized by its transmission and reflections of light intensities

3.18
coated interface
interface that has one or more thin films, with the entire stack of thin films being characterized by its resulting transmission and reflection of light intensities

4 Symbols

D65	standard illuminant D65
UV	ultraviolet radiation
τ_{UV}	ultraviolet transmittance
$\tau(\lambda)$	spectral transmittance
$\rho(\lambda)$	spectral reflectance

τ_V	light transmittance
ρ_v	light reflectance
τ_e	solar direct transmittance
ρ_e	solar direct reflectance
g	total solar energy transmittance
R_a	general colour rendering index in transmission
D_λ	relative spectral distribution of illuminant D65
$V(\lambda)$	spectral luminous efficiency
α_e	solar direct absorptance
Φ_e	incident solar radiant flux
q_i	secondary internal heat transfer factor
q_e	secondary external heat transfer factor
α_{elec}	proportion of total absorbed solar radiation that is extracted from the PV cell-covered area of a BIPV glazing unit as electricity
S_λ	relative spectral distribution of solar radiation
h_e	external heat transfer coefficient
h_i	internal heat transfer coefficient
ε	corrected emissivity
Λ	thermal conductance
λ	wavelength
$\Delta\lambda$	wavelength interval
U_λ	relative spectral distribution of UV in solar radiation
SC	shading coefficient
τ_{df}	CIE damage factor
F_{sd}	skin damage factor
$I(\lambda)$	spectral normalised radiant flow
η_{mod}	photovoltaic conversion efficiency of a planar PV module
A	surface area
r	reflectance on interface
CR	coverage ratio
$\eta_{cell,mod}$	power conversion efficiency of a hypothetical planar PV module with 100 % cell coverage ratio

5 Determination of characteristics

5.1 General

The characteristics are determined for quasi-parallel, near normal radiation incidence (see Reference [4]) using the radiation distribution of illuminant D65 (see Table 1), solar radiation in accordance with Table 2, ultraviolet (UV) radiation in accordance with Table 3, CIE damage function in accordance with Table 4 and skin damage function in accordance with Table 5.

The characteristics are as follows:

— the spectral transmittance $\tau(\lambda)$ and the spectral reflectance $\rho(\lambda)$ in the wavelength range from 300 nm to 2 500 nm;

— the light transmittance τ_v and the light reflectance ρ_v for illuminant D65;

— the solar direct transmittance τ_e and the solar direct reflectance ρ_e;

— the total solar energy transmittance g;

— the UV-transmittance τ_{UV};

— the general colour rendering index in transmission R_a;

— the total shading coefficient, SC;

— CIE damage factor τ_{df};

— skin damage factor F_{sd}.

To characterize glazing, the principal parameters are τ_v and g; the other parameters are optional to provide additional information.

If the value of a given characteristic is to be calculated for different glass thicknesses (in the case of uncoated glass) or for the same coating applied to different substrates, it shall be obtained by calculation in accordance with Annex A.

A procedure for the calculation of the spectral characteristics of laminated glass is given in Annex B.

Guidelines on determining the spectral characteristics of screen-printed glass are given in Annex C.

A modified matrix method is provided as an alternative calculation method in Annex D.

Modifications to the formulae to permit calculation and declaration of the luminous and solar properties of BIPV glazing are given in Annex E.

The convention adopted in this document is for the incident radiation to be from left to right. The left side is also referred to as outside or outdoors, whereas the right side is also referred to as inside or indoors.

The use of an integrating sphere is necessary when light scattering materials are tested. In this case the size of the sphere and its aperture should be large enough to collect all possible scattered light and to obtain fair average values when surface patterns are irregularly distributed.

5.2 Insulating glass unit optical calculation

In the case of an insulating glass unit, the spectral transmittance $\tau(\lambda)$, the spectral reflectance $\rho(\lambda)$ and the spectral absorptance $\alpha_j^T(\lambda)$ of the j^{th} pane in the glazing unit are calculated from the spectral transmittances and reflectances of the individual components using Formulae (1) to (5):

For double glazing:

$$\tau(\lambda) = \frac{\tau_1(\lambda) \cdot \tau_2(\lambda)}{1 - \rho_1'(\lambda) \cdot \rho_2(\lambda)} \tag{1}$$

$$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda) \cdot \rho_2(\lambda)}{1 - \rho_1'(\lambda) \cdot \rho_2(\lambda)} \tag{2}$$

$$\rho'(\lambda) = \rho'_2(\lambda) + \frac{\tau_2^2(\lambda) \cdot \rho_1'(\lambda)}{1 - \rho_1'(\lambda) \cdot \rho_2(\lambda)} \tag{3}$$

$$\alpha_1^T(\lambda) = \alpha_1(\lambda) + \frac{\tau_1(\lambda) \cdot \rho_2(\lambda) \cdot \alpha_1'(\lambda)}{1 - \rho_1'(\lambda) \cdot \rho_2(\lambda)} \tag{4}$$

$$\alpha_2^T(\lambda) = \frac{\tau_1(\lambda) \cdot \alpha_2(\lambda)}{1 - \rho_1'(\lambda) \cdot \rho_2(\lambda)} \tag{5}$$

where

$\tau(\lambda)$	is the spectral transmittance of the double glazing;
$\rho(\lambda)$	is the spectral reflectance of the double glazing for external incident radiation;
$\rho'(\lambda)$	is the spectral reflectance of the double glazing for internal incident radiation;
$\alpha_1^T(\lambda)$	is the spectral absorptance of the first (outer) pane in the double glazing for external incident radiation;
$\alpha_2^T(\lambda)$	is the spectral absorptance of the second (inner) pane in the double glazing for external incident radiation;
$\tau_1(\lambda)$	is the spectral transmittance of the first (outer) pane;
$\rho_1(\lambda)$	is the spectral reflectance of the first (outer) pane, measured in the direction of incident radiation;
$\rho_1'(\lambda)$	is the spectral reflectance of the first (outer) pane, measured in the direction opposite to the incident radiation;
$\tau_2(\lambda)$	is the spectral transmittance of the second pane;
$\rho_2(\lambda)$	is the spectral reflectance of the second pane, measured in the direction of the incident radiation;
$\rho_2'(\lambda)$	is the spectral reflectance of the second pane, measured in the direction opposite to the incident radiation;
$\alpha_1(\lambda)$	is the spectral direct absorptance of the outer pane, measured in the direction of the incident radiation, given by Formula (6):

$$\alpha_1(\lambda) = 1 - \tau_1(\lambda) - \rho_1(\lambda) \tag{6}$$

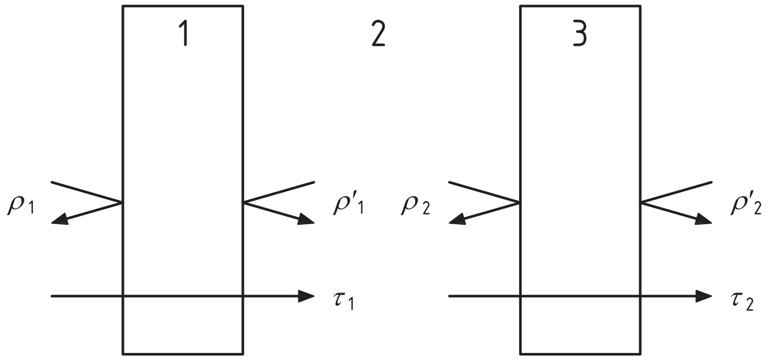
$\alpha_1'(\lambda)$	is the spectral direct absorptance of the outer pane, measured in the opposite direction to the incident radiation, given by Formula (7):

$$\alpha_1'(\lambda) = 1 - \tau_1(\lambda) - \rho_1'(\lambda) \tag{7}$$

$\alpha_2(\lambda)$ is the spectral direct absorptance of the second pane, measured in the direction of the incident radiation, given by Formula (8):

$$\alpha_2(\lambda) = 1 - \tau_2(\lambda) - \rho_2(\lambda) \tag{8}$$

The above is illustrated in Figure 1.



Key

1 pane 1
2 cavity
3 pane 2

Figure 1 — Transmittance and reflectance in a double glazing insulating glass unit

For triple glazing, Formulae (9) to (14) apply.

$$\tau(\lambda) = \frac{\tau_1(\lambda)\cdot\tau_2(\lambda)\cdot\tau_3(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{9}$$

$$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\cdot\rho_2(\lambda)\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]+\tau_1^2(\lambda)\cdot\tau_2^2(\lambda)\cdot\rho_3(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{10}$$

$$\rho'(\lambda) = \rho_3'(\lambda) + \frac{\tau_3^2(\lambda)\cdot\rho_2'(\lambda)\cdot\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]+\tau_3^2(\lambda)\cdot\tau_2^2(\lambda)\cdot\rho_1'(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{11}$$

$$\alpha_1^T(\lambda) = \alpha_1(\lambda) + \frac{\tau_1(\lambda)\cdot\alpha_1'(\lambda)\cdot\rho_2(\lambda)\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]+\tau_1(\lambda)\cdot\tau_2^2(\lambda)\cdot\alpha_1'(\lambda)\cdot\rho_3(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{12}$$

$$\alpha_2^T(\lambda) = \frac{\tau_1(\lambda)\cdot\alpha_2(\lambda)\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]+\tau_1(\lambda)\cdot\tau_2(\lambda)\cdot\alpha_2'(\lambda)\cdot\rho_3(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{13}$$

$$\alpha_3^T(\lambda) = \frac{\tau_1(\lambda)\cdot\tau_2(\lambda)\cdot\alpha_3(\lambda)}{\left[1-\rho_1'(\lambda)\cdot\rho_2(\lambda)\right]\cdot\left[1-\rho_2'(\lambda)\cdot\rho_3(\lambda)\right]-\tau_2^2(\lambda)\cdot\rho_1'(\lambda)\cdot\rho_3(\lambda)} \tag{14}$$

where

$\tau(\lambda)$ is the spectral transmittance of the triple glazing;

$\rho(\lambda)$ is the spectral reflectance of the triple glazing for external incident radiation;

$\rho'(\lambda)$ is the spectral reflectance of the triple glazing for internal incident radiation;

$\alpha_1^T(\lambda)$ is the spectral absorptance of the first (outer) pane in the triple glazing for external incident radiation;

$\alpha_2^T(\lambda)$ is the spectral absorptance of the second (middle) pane in the triple glazing for external incident radiation;

$\alpha_3^T(\lambda)$ is the spectral absorptance of the third (inner) pane in the triple glazing for external incident radiation;

$\tau_1(\lambda)$, $\rho_1(\lambda)$, $\rho_1'(\lambda)$, $\tau_2(\lambda)$, $\rho_2(\lambda)$, $\rho_2'(\lambda)$, $\alpha_1(\lambda)$, $\alpha_1'(\lambda)$ and $\alpha_2(\lambda)$ are explained in Formula (1) to Formula (5);

$\tau_3(\lambda)$ is the spectral transmittance of the third pane;

$\rho_3(\lambda)$ is the spectral reflectance of the third pane, measured in the direction of the incident radiation;

$\rho_3'(\lambda)$ is the spectral reflectance of the third pane, measured in the direction opposite to the incident radiation;

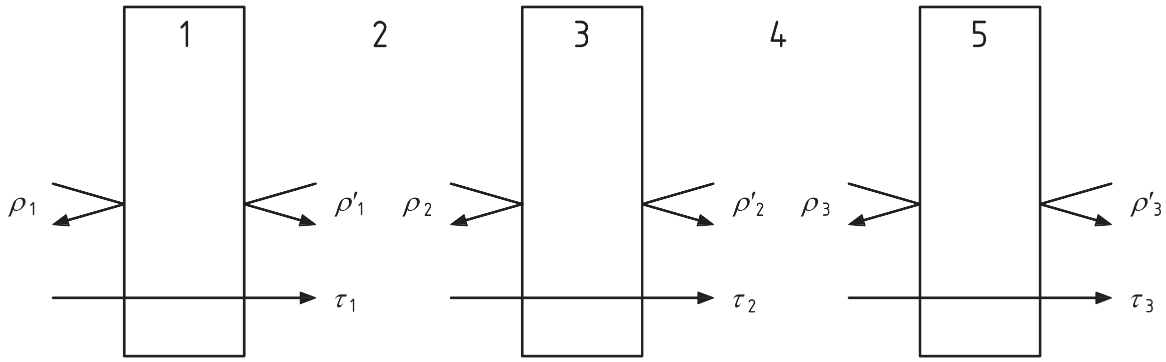
$\alpha_2'(\lambda)$ is the spectral direct absorptance of the second pane, measured in the opposite direction to the incident radiation, given by Formula (15):

$$\alpha_2'(\lambda) = 1 - \tau_2(\lambda) - \rho_2'(\lambda) \quad (15)$$

$\alpha_3(\lambda)$ is the spectral direct absorptance of the third pane, measured in the direction of the incident radiation, given by Formula (16):

$$\alpha_3(\lambda) = 1 - \tau_3(\lambda) - \rho_3(\lambda) \quad (16)$$

The above is illustrated in Figure 2.



Key

1 pane 1
2 cavity 1
3 pane 2
4 cavity 2
5 pane 3

Figure 2 — Transmittance and reflectance in a triple glazing insulating glass unit

For glazing with more than three components, formulae similar to Formula (1) to Formula (5) and Formula (9) to Formula (14) are found to calculate $\tau(\lambda)$ of such glazing from the spectral coefficients of the individual components. As an example, glazing composed of five components may be treated as follows:

a) first consider the first three components as triple glazing and calculate the spectral characteristics of this combination;

b) next, run the same procedure for the next two components as double glazing;

c) then calculate $\tau(\lambda)$ for the five-component glazing, considering it as double glazing consisting of the preceding triple and double glazing (or, alternatively, the methodology in Annex D can be followed).

NOTE Measurement of light scattering glass products is the subject of a round robin test programme under the responsibility of International Commission on Glass, Technical Committee 10. The results of this programme are expected to include suggestions for improvements in measurement and prediction techniques.

5.3 Light transmittance and reflectance

The light transmittance τ_v and reflectance ρ_v of the glazing are calculated using Formulae (17) and (18):

$$\tau_v = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda} \tag{17}$$

$$\rho_v = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot \rho(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda} \tag{18}$$

where

D_λ is the relative spectral distribution of illuminant D65 (see Reference [6]);

$\tau(\lambda)$ is the spectral transmittance of the glazing;

$\rho(\lambda)$ is the spectral reflectance of the glazing;

$V(\lambda)$ is the spectral luminous efficiency for photopic vision defining the standard observer for photometry (see Reference [6]);

$\Delta\lambda$ is the wavelength interval.

Table 1 indicates the values for $D_\lambda \cdot V(\lambda) \cdot \Delta\lambda$ for wavelength intervals of 10 nm. The table has been drawn up in such a way that $\sum D_\lambda \cdot V(\lambda) \cdot \Delta\lambda = 1$.

For calculating the internal light reflectance $\rho'(\lambda)$ is used instead of $\rho(\lambda)$ in Formula (18).

5.4 Solar direct transmittance, reflectance and absorptance

The solar direct transmittance τ_e, the solar direct reflectance ρ_e and the solar direct absorptance $\alpha_{e,j}$ of the glazing are calculated using Formulae (19), (20) and (21):

$$\tau_e = \frac{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{\lambda=300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \cdot \Delta\lambda} \tag{19}$$