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Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors

Verre dans la construction — Détermination de la transmission lumineuse, de la transmission solaire directe, de la transmission énergétique solaire totale, de la transmission de l'ultraviolet et des facteurs dérivés des vitrages

Reference number
ISO 9050:2003(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

International Standards are drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The main task of technical committees is to prepare International Standards. Draft International Standards adopted by the technical committees are circulated to the member bodies for voting. Publication as an International Standard requires approval by at least 75 % of the member bodies casting a vote.

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

ISO 9050 was prepared by Technical Committee ISO/TC 160, *Glass in building*, Subcommittee SC 2, *Use considerations*.

This second edition cancels and replaces the first edition (ISO 9050:1990), which has been technically revised.

INTERNATIONAL STANDARD **ISO 9050:2003(E)**

Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors

1 Scope

This International Standard specifies methods of determining light and energy transmittance of solar radiation for glazing in buildings. These characteristic data can serve as a basis for light, heating and ventilation calculations of rooms and can permit comparison between different types of glazing.

This International Standard is applicable both to conventional glazing units and to absorbing or reflecting solar-control glazing, used as glazed apertures. The appropriate formulae for single, double and triple glazing are given. Furthermore, the general calculation procedures for units consisting of more than components are established.

This International Standard is applicable to all transparent materials. One exception is the treatment of the secondary heat transfer factor and the total solar energy factor for those materials that show significant transmittance in the wavelength region of ambient temperature radiation (5 µm to 50 µm), such as certain plastic sheets.

NOTE For multiple glazing including elements with light-scattering properties, the more detailed procedures of ISO 15099 can be used. For daylighting calculations, procedures can be found in reference [1].

2 Normative references

The following referenced documents are indispensable for the application 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 9845-1:1992, *Solar energy — Reference solar spectral irradiance at the ground at different receiving conditions — Part 1: Direct normal and hemispherical solar irradiance for air mass 1,5*

ISO 10291:1994, *Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Guarded hot plate method*

ISO 10292:1994, *Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing*

ISO 10293:1997, *Glass in building — Determination of steady-state U values (thermal transmittance) of multiple glazing — Heat flow meter method*

ISO 10526:1999/CIE S005:1998, *CIE standard illuminants for colorimetry*

ISO/CIE 10527:1991, *CIE standard colorimetric observers*

CIE 13.3:1995, *Technical report — Method of measuring and specifying colour rendering properties of light source*

3 Determination of characteristic parameters

3.1 General

The characteristic parameters are determined for quasi-parallel, almost normal radiation incidence. For the measurements, the samples shall be irradiated by a beam whose axis is at an angle not exceeding 10° from the normal to the surface. The angle between the axis and any ray of the illuminating beam shall not exceed 5° (see reference [2]).

The characteristic parameters are as follows:

- the spectral transmittance $\tau(\lambda)$, the spectral external reflectance $\rho_o(\lambda)$ and the spectral internal reflectance $\rho_i(\lambda)$ in the wavelength range of 300 nm to 2 500 nm;
- the light transmittance τ_v, the external light reflectance $\rho_{v,o}$ and the internal light reflectance $\rho_{v,i}$ for illuminant D65;
- the solar direct transmittance τ_e and the solar direct reflectance ρ_e;
- the total solar energy transmittance (solar factor) g;
- the UV-transmittance τ_{UV};
- the general colour rendering index R_a.

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

If nothing else is stated, the published characteristic parameters shall be determined using the standard conditions given in 3.3 to 3.7. Other optional conditions given in Clause 4 shall be stated.

When calculating the characteristic parameters of multiple glazing, the spectral data of each glass component instead of integrated data shall be used.

3.2 Performance of optical measurements

Optical measurements in transmission and reflection require special care and much experimental experience to achieve an accuracy in transmittance and reflectance of about ± 0,01.

Commercial spectrophotometers (with or without integrating spheres) are affected by various sources of inaccuracy when used for reflectance and transmittance measurements on flat glass for building.

The wavelength calibration and the photometric linearity of commercial spectrophotometers shall be checked periodically using reference materials obtained from metrological laboratories.

The wavelength calibration shall be performed by measuring glass plates or solutions which feature relatively sharp absorption bands at specified wavelengths; the photometric linearity shall be checked using grey filters with a certified transmittance.

For reflectance measurements, reference materials having a reflection behaviour (i.e. reflectance level and ratio of diffuse and direct reflectance) similar to the unknown sample shall be selected.

Thick samples (e.g. laminated glass or insulating units) can modify the optical path of the instrument's beam as compared to the path in air and therefore the sample beam hits an area of the detector having a different responsivity.

A similar source of inaccuracy occurs in case of samples with significant wedge angles which deflect the transmitted (and reflected) beams. It is recommended to check the reproducibility by repeating the measurement after rotating the sample.

Additionally, in the case of reflectance measurements, glass sheets cause a lateral shear of the beam reflected by the second surface, causing reflectance losses (whose extent is particulary evident in the case of thick and/or wedged samples). This source of inaccuracy shall be taken into account particularly in the case of reflectance measurements through the uncoated side. In order to quantify and correct systematic errors, it is recommended to use calibrated reflectance standards with a thickness similar to the unknown sample.

In the case of diffusing samples (or samples with a non-negligible diffusing component or wedged samples), transmittance and reflectance measurements shall be performed using integrating spheres whose openings are sufficiently large to collect all the diffusely transmitted or reflected beam. The sphere diameter shall be adequate and the internal surface adequately coated with a highly diffusing reflectance material, so that the internal area can provide the necessary multiple reflections. Reference materials with characteristics similar to the unknown sample as specified above shall be used.

If the transmittance or reflectance curve recorded by the spectrometer exhibits a high level of noise for some wavelengths, the values to be considered for those wavelengths should be obtained after a smoothing of the noise.

In this International Standard, these requirements are not all treated in detail. For more information, see reference [3] which gives comprehensive and detailed information on how to perform optical measurements.

3.3 Light transmittance

The light transmittance τ_v of glazing shall be calculated using the following formula:

$$\tau_\mathrm{v} = \frac{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} \tau(\lambda)\, D_\lambda\, V(\lambda)\, \Delta\lambda}{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda\, V(\lambda)\, \Delta\lambda} \qquad (1)$$

where

D_λ is the relative spectral distribution of illuminant D65 (see ISO/CIE 10526),

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

$V(\lambda)$ is the spectral luminous efficiency for photopic vision defining the standard observer for photometry (see ISO/CIE 10527);

$\Delta\lambda$ is the wavelength interval.

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

In the case of multiple glazing, the spectral transmittance $\tau(\lambda)$ shall be obtained by calculation from the spectral characteristics of the individual components. Alternatively measurements on non-diffusing multiple units may be performed using an integrating sphere. This may be achieved after reducing the interspaces under conditions that allow the collection of the whole transmitted beam (see 3.2).

The calculation of the spectral transmittance $\tau(\lambda)$ shall be performed using methods such as algebraic manipulation, the embedding technique of reference [4] or by recursion techniques (e.g. according to reference [5]). Any algorithm that can be shown to yield consistently the correct solution is acceptable.

For the calculation of $\tau(\lambda)$ as well as for the calculation of spectral reflectance (see 3.4), the following symbols for the spectral transmittance and spectral reflectance of the individual components are used:

$\tau_1(\lambda)$ is the spectral transmittance of the outer (first) pane;

$\tau_2(\lambda)$ is the spectral transmittance of the second pane;

$\tau_n(\lambda)$ is the spectral transmittance of the nth (inner) pane (e.g. for triple glazing $n = 3$);

$\rho_1(\lambda)$ is the spectral reflectance of the outer (first) pane measured in the direction of incident radiation;

$\rho'_1(\lambda)$ is the spectral reflectance of the outer (first) pane measured in the opposite direction of incident radiation;

$\rho_2(\lambda)$ is the spectral reflectance of the second pane measured in the direction of incident radiation;

$\rho'_2(\lambda)$ is the spectral reflectance of the second pane measured in the opposite direction of incident radiation;

$\rho_n(\lambda)$ is the spectral reflectance of the nth (inner) pane measured in the direction of incident radiation;

$\rho'_n(\lambda)$ is the spectral reflectance of the nth (inner) pane measured in the opposite direction of incident radiation.

For the spectral transmittance $\tau(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are obtained.

a) For double glazing:

$$\tau(\lambda) = \frac{\tau_1(\lambda)\,\tau_2(\lambda)}{1 - \rho'_1(\lambda)\,\rho_2(\lambda)} \tag{2}$$

b) For triple glazing:

$$\tau(\lambda) = \frac{\tau_1(\lambda)\,\tau_2(\lambda)\,\tau_3(\lambda)}{\left[1 - \rho'_1(\lambda)\,\rho_2(\lambda)\right]\cdot\left[1 - \rho'_2(\lambda)\,\rho_3(\lambda)\right] - \tau_2^2(\lambda)\,\rho'_1(\lambda)\,\rho_3(\lambda)} \tag{3}$$

For multiple glazing with more than three components, relationships similar to Equations (2) and (3) are found to calculate $\tau(\lambda)$ of such glazing from the spectral characteristics of the individual components. As these formulae become very complex, they are not given here.

As an example for calculating $\tau(\lambda)$ according to the procedures of this International Standard, a glazing composed of five components may be treated as follows:

- first consider the first three components as triple glazing and calculate the spectral characteristics of this combination;
- next, run the same procedure for the next two components as double glazing;
- then calculate $\tau(\lambda)$ for the five component glazing, considering it as double glazing consisting of the preceding triple and double glazing.

3.4 Light reflectance

3.4.1 External light reflectance of glazing

The external light reflectance of glazing $\rho_{\mathrm{v,o}}$ shall be calculated using the following formula:

$$\rho_{\mathrm{v,o}} = \frac{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} \rho_{\mathrm{o}}(\lambda)\, D_\lambda\, V(\lambda)\, \Delta\lambda}{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda\, V(\lambda)\, \Delta\lambda} \tag{4}$$

where $\rho_{\mathrm{o}}(\lambda)$ is the spectral external reflectance of glazing, and D_λ, $V(\lambda)$, $\Delta\lambda$ and the integration procedure are as defined in 3.3

For multiple glazing, the calculation of the spectral external reflectance $\rho_{\mathrm{o}}(\lambda)$ shall be performed using the same methods as given in 3.3 for the calculation of the spectral transmittance $\tau(\lambda)$.

For the spectral external reflectance $\rho_{\mathrm{o}}(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are applied.

a) For double glazing:

$$\rho_{\mathrm{o}}(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\, \rho_2(\lambda)}{1 - \rho_1'(\lambda)\, \rho_2(\lambda)} \tag{5}$$

b) For triple glazing:

$$\rho_{\mathrm{o}}(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\, \rho_2(\lambda)\left[1 - \rho_2'(\lambda)\, \rho_3(\lambda)\right] + \tau_1^2(\lambda)\, \tau_2^2(\lambda)\, \rho_3(\lambda)}{\left[1 - \rho_1'(\lambda)\, \rho_2(\lambda)\right]\cdot\left[1 - \rho_2'(\lambda)\, \rho_3(\lambda)\right] - \tau_2^2(\lambda)\, \rho_1'(\lambda)\, \rho_3(\lambda)} \tag{6}$$

For multiple glazing with more than three components, relationships similar to Equations (5) and (6) are found to calculate $\rho_{\mathrm{o}}(\lambda)$ of such glazing from the spectral characteristics of the individual components. As these formulae become very complex, they are not given here.

As an example for calculating $\rho_{\mathrm{o}}(\lambda)$, a glazing composed of five components may be treated in the same way as described in 3.3.

3.4.2 Internal light reflectance of glazing

The internal light reflectance of glazing $\rho_{\mathrm{v,i}}$ shall be calculated using the following formula:

$$\rho_{\mathrm{v,i}} = \frac{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} \rho_{\mathrm{i}}(\lambda) D_\lambda\ V(\lambda)\, \Delta\lambda}{\sum\limits_{\lambda = 380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda\, V(\lambda)\, \Delta\lambda} \tag{7}$$

where ρ_{i} (λ) is the spectral internal reflectance of glazing, and $D_{\lambda,}$ $V(\lambda)$, $\Delta\lambda$ and the integration procedure are as defined in 3.3.

For multiple glazing, the calculation of the spectral internal reflectance $\rho_{\mathrm{i}}(\lambda)$ shall be performed using the same methods as given in 3.3 for the calculation of the spectral transmittance $\tau(\lambda)$.

For the spectral internal reflectance $\rho_{\mathrm{i}}(\lambda)$ as a function of the spectral characteristics of the individual components of the unit, the following formulae are applied.

a) For double glazing:

$$\rho_{\mathrm{i}}(\lambda) = \rho'_2(\lambda) + \frac{\tau_2^2(\lambda)\,\rho'_1(\lambda)}{1 - \rho'_1(\lambda)\quad \rho_2(\lambda)} \tag{8}$$

b) For triple glazing:

$$\rho_{\mathrm{i}}(\lambda) = \rho'_3(\lambda) + \frac{\tau_3^2(\lambda)\,\rho'_2(\lambda)\left[1 - \rho_2(\lambda)\,\rho'_1(\lambda)\right] + \tau_3^2(\lambda)\,\tau_2^2(\lambda)\,\rho'_1(\lambda)}{\left[1 - \rho_3(\lambda)\,\rho'_2(\lambda)\right]\cdot\left[1 - \rho_2(\lambda)\,\rho'_1(\lambda)\right] - \tau_2^2(\lambda)\,\rho_3(\lambda)\,\rho'_1(\lambda)} \tag{9}$$

For multiple glazing with more than three components, relationships similar to Equations (8) and (9) are found to calculate $\rho_{\mathrm{i}}(\lambda)$ of such glazing from the spectral characteristics of the individual components. As these formulae are very complex, they are not given here.

As an example for calculating $\rho_{\mathrm{i}}(\lambda)$, a glazing composed of five components may be treated in the same way as described in 3.3.

3.5 Total solar energy transmittance (solar factor)

3.5.1 General

The total solar energy transmittance g is the sum of the solar direct transmittance τ_{e} and the secondary heat transfer factor q_{i} towards the inside (see 3.5.3 and 3.5.6), the latter resulting from heat transfer by convection and longwave IR-radiation of that part of the incident solar radiation which has been absorbed by the glazing:

$$g = \tau_{\mathrm{e}} + q_{\mathrm{i}} \tag{10}$$

3.5.2 Division of incident solar radiation flux

The incident solar radiant flux per unit area ϕ_{e} is divided into the following three parts (see Figure 1):

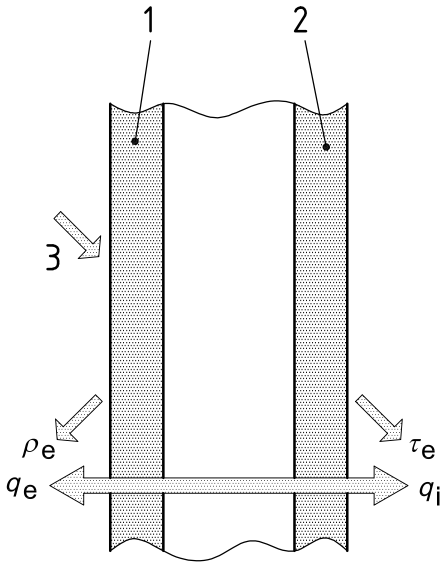
- the transmitted part $\tau_{\mathrm{e}}\phi_{\mathrm{e}}$;
- the reflected part $\rho_{\mathrm{e}}\phi_{\mathrm{e}}$;
- the absorbed part $\alpha_{\mathrm{e}}\phi_{\mathrm{e}}$;

where

τ_{e} is the solar direct transmittance (see 3.5.3);

ρ_{e} is the solar direct reflectance (see 3.5.4);

α_{e} is the solar direct absorptance (see 3.5.5).



Key

1 outer pane
2 second inner pane
3 unit incident radiant flux

$\rho_e = 0{,}38$; $q_e = 0{,}17$

$\tau_e = 0{,}41$; $q_i = 0{,}04$; therefore $g = 0{,}45$

Figure 1 — Division of the incident radiant flux for a double glazing unit

The relationship between the three characteristics is

$$\tau_e + \rho_e + \alpha_e = 1 \tag{11}$$

The absorbed part $\alpha_e \phi_e$ is subsequently divided into two parts $q_i \phi_e$ and $q_e \phi_e$, which are energy transferred to the inside and outside respectively:

$$\alpha_e = q_i + q_e \tag{12}$$

where

q_i is the secondary heat transfer factor of the glazing towards the inside;

q_e is the secondary heat transfer factor of the glazing towards the outside.

3.5.3 Solar direct transmittance

The solar direct transmittance τ_e of glazing shall be calculated using the following formula:

$$\tau_e = \frac{\sum\limits_{\lambda = 300\text{ nm}}^{2\,500\text{ nm}} \tau(\lambda) S_\lambda \, \Delta\lambda}{\sum\limits_{\lambda = 300\text{ nm}}^{2\,500\text{ nm}} S_\lambda \Delta\lambda} \tag{13}$$

where

S_λ is the relative spectral distribution of the solar radiation;

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

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 2.

The relative spectral distribution, S_λ, used to calculate the solar direct transmittance τ_e, is derived from the global solar irradiance given in ISO 9845-1:1992, Table 1, column 5. The corresponding values $S_\lambda\Delta\lambda$ are given in Table 2. This table is drawn up in such a way that $\Sigma\, S_\lambda\Delta\lambda = 1$.

In the case of multiple glazing, the spectral transmittance $\tau(\lambda)$ is calculated in accordance with 3.3.

NOTE Contrary to real situations, it is always assumed, for simplification, that the solar radiation strikes the glazing as a beam and almost at normal incidence. In the case of oblique incidence of radiation, the solar direct transmittance of glazing and the total solar energy transmittance are both somewhat reduced. The solar control effect becomes greater in the case of oblique incidence of radiation.

3.5.4 Solar direct reflectance

The solar direct reflectance ρ_e of the glazing shall be calculated using the following formula:

$$\rho_e = \frac{\sum_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \rho_o(\lambda)\, S_\lambda\, \Delta\lambda}{\sum_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\, \Delta\lambda} \tag{14}$$

where

S_λ is the relative spectral distribution of the solar radiation (see 3.5.3);

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

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 2.

In the case of multiple glazing, the spectral external reflectance $\rho_o(\lambda)$ is calculated in accordance with 3.4.1.

3.5.5 Solar direct absorptance

The solar direct absorptance α_e shall be calculated from Equation (11).

3.5.6 Secondary heat transfer factor towards the inside

3.5.6.1 Boundary conditions

For the calculation of the secondary heat transfer factor towards the inside, q_i, the heat transfer coefficients of the glazing towards the outside, h_e, and towards the inside, h_i, are needed. These values mainly depend on the position of the glazing, wind velocity, inside and outside temperatures and, furthermore, on the temperature of the two external glazing surfaces.

As the purpose of this International Standard is to provide basic information on the performance of glazing, the following conventional conditions have been stated for simplicity:

- position of the glazing: vertical;
- outside surface: wind velocity approximately 4 m/s; corrected emissivity 0,837;
- inside surface: natural convection; emissivity optional;
- air spaces are unventilated.

Under these conventional, average conditions, standard values for h_e and h_i are obtained:

$$h_\mathrm{e} = 23\ \mathrm{W/(m^2 \cdot K)}$$

$$h_\mathrm{i} = \left(3{,}6 + \frac{4{,}4\varepsilon_\mathrm{i}}{0{,}837}\right)\ \mathrm{W/(m^2 \cdot K)}$$

where ε_i is the corrected emissivity of the inside surface [for soda lime glass, $\varepsilon_\mathrm{i} = 0{,}837$ and $h_\mathrm{i} = 8\ \mathrm{W/(m^2 \cdot K)}$].

The corrected emissivity is defined and measured according to ISO 10292.

If other boundary conditions are used to meet special requirements they shall be stated in the test report.

Values for ε_i lower than 0,837 (due to surface coatings with higher reflectance in the far infrared) should only to be taken into account if condensation on the coated surface can be excluded.

3.5.6.2 Single glazing

The secondary heat transfer factor towards the inside, q_i, of single glazing shall be calculated using the following formula:

$$q_\mathrm{i} = \alpha_\mathrm{e} \frac{h_\mathrm{i}}{h_\mathrm{e} + h_\mathrm{i}} \tag{15}$$

where

α_e is the solar direct absorptance in accordance with 3.5.2;

h_e, h_i are the heat transfer coefficients towards the outside and inside, respectively, in accordance with 3.5.6.1.

3.5.6.3 Double glazing

The secondary heat transfer factor towards the inside, q_i, of double glazing shall be calculated using the following formula:

$$q_\mathrm{i} = \frac{\left(\dfrac{\alpha_\mathrm{e1} + \alpha_\mathrm{e2}}{h_\mathrm{e}} + \dfrac{\alpha_\mathrm{e2}}{\Lambda}\right)}{\left(\dfrac{1}{h_\mathrm{i}} + \dfrac{1}{h_\mathrm{e}} + \dfrac{1}{\Lambda}\right)} \tag{16}$$

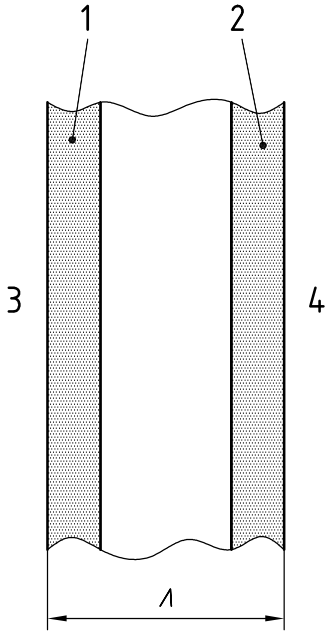
where

α_{e1} is the solar direct absorptance of the outer (first) pane within the double glazing;

α_{e2} is the solar direct absorptance of the second pane within the double glazing;

Λ is the thermal conductance between the outer surface and the innermost surface of the double glazing (see Figure 2), in watts per square metre kelvin (W/m^2·K);

h_e, h_i are the heat transfer coefficients towards the outside and the inside respectively in accordance with 3.5.6.1.



Key

1 pane 1
2 pane 2
3 outside
4 inside

Figure 2 — Illustration of the meaning of thermal conductance Λ

Characteristics α_{e1} and α_{e2} are calculated as follows:

$$\alpha_{e1} = \frac{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \left\{ \alpha_1(\lambda) + \frac{\alpha'_1(\lambda)\, \tau_1(\lambda)\, \rho_2(\lambda)}{1 - \rho'_1(\lambda)\, \rho_2(\lambda)} \right\} S_\lambda\, \Delta\lambda}{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\, \Delta\lambda} \tag{17}$$

$$\alpha_{e2} = \frac{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \left\{ \frac{\alpha_2(\lambda)\, \tau_1(\lambda)}{1 - \rho'_1(\lambda)\, \rho_2(\lambda)} \right\} S_\lambda\, \Delta\lambda}{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\, \Delta\lambda} \tag{18}$$

where $\tau_1(\lambda)$, $\tau_2(\lambda)$, $\rho_1(\lambda)$, $\rho'_1(\lambda)$, $\rho_2(\lambda)$ are as defined in 3.3.

$\alpha_1(\lambda)$ is the spectral direct absorptance of the outer pane, measured in the direction of the incident radiation, given by the relationship

$$\alpha_1(\lambda) = 1 - \tau_1(\lambda) - \rho_1(\lambda) \tag{19}$$

$\alpha'_1(\lambda)$ is the spectral direct absorptance of the outer pane, measured in the opposite direction to the incident radiation, given by the relationship

$$\alpha'_1(\lambda) = 1 - \tau_1(\lambda) - \rho'_1(\lambda) \tag{20}$$

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

$$\alpha_2(\lambda) = 1 - \tau_2(\lambda) - \rho_2(\lambda) \tag{21}$$

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 2.

The thermal conductance Λ shall be determined for a temperature difference of $\Delta T = 15$ °C across the sample and a mean temperature of the sample of 10 °C by the calculation method given in ISO 10292, or by measuring methods using the guarded hot-plate method ISO 10291, or the heat flow meter method ISO 10293. The recommended procedure is the calculation procedure.

If another temperature difference ΔT across the sample and/or another mean temperature of the sample is used for the determination of the thermal conductance Λ to meet special requirements, this shall be stated in the test report (see Clause 4).

3.5.6.4 Multiple glazing with $n > 2$ components

The secondary heat transfer factor towards the inside, q_i, of a multiple glazing with more than two components shall be calculated using the following formula:

$$q_\mathrm{i} = \frac{\dfrac{\alpha_{\mathrm{e}1} + \alpha_{\mathrm{e}2} + \alpha_{\mathrm{e}3} + \cdots + \alpha_{\mathrm{e}n}}{h_\mathrm{e}} + \dfrac{\alpha_{\mathrm{e}2} + \alpha_{\mathrm{e}3} + \cdots + \alpha_{\mathrm{e}n}}{\Lambda_{12}} + \dfrac{\alpha_{\mathrm{e}3} + \cdots + \alpha_{\mathrm{e}n}}{\Lambda_{23}} + \cdots + \dfrac{\alpha_{\mathrm{e}n}}{\Lambda_{(n-1)n}}}{\dfrac{1}{h_\mathrm{i}} + \dfrac{1}{h_\mathrm{e}} + \dfrac{1}{\Lambda_{12}} + \dfrac{1}{\Lambda_{23}} + \cdots + \dfrac{1}{\Lambda_{(n-1)n}}} \tag{22}$$

where

$\alpha_{\mathrm{e}1}$ is the solar direct absorptance of the outer (first) pane within the n-fold glazing;

$\alpha_{\mathrm{e}2}$ is the solar direct absorptance of the second pane within the n-fold glazing;

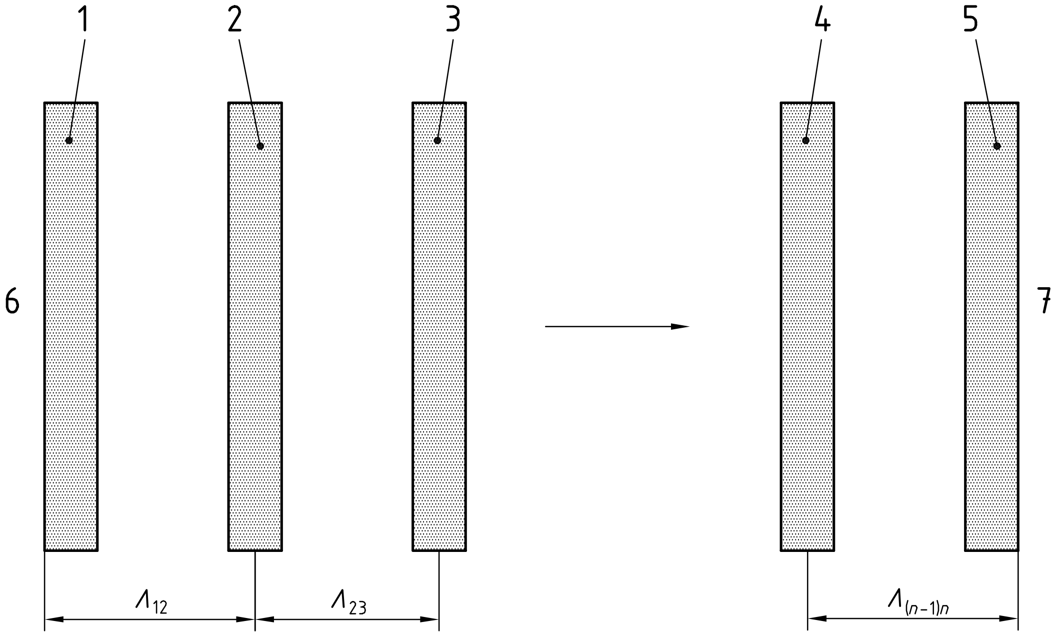
$\alpha_{\mathrm{e}n}$ is the solar direct absorptance of the nth (inner) pane of the n-fold glazing;

h_e, h_i are the heat transfer coefficients towards the outside and towards the inside respectively in accordance with 3.5.6.1;

Λ_{12} is the thermal conductance between the outer surface of the outer (first) pane and the centre of the second pane (see Figure 3);

Λ_{23} is the thermal conductance between the centre of the second pane and the centre of the third pane (see Figure 3);

$\Lambda_{(n-1)n}$ is the thermal conductance between the centre of the $(n - 1)$th pane and the outer surface of the nth (inner) pane (see Figure 3).



Key

1 pane 1
2 pane 2
3 pane 3
4 pane (n – 1)
5 pane n
6 outside
7 inside

NOTE For triple glazing, pane 3 corresponds to pane n.

Figure 3 — Illustration of the meaning of the thermal conductances $\Lambda_{12}, \Lambda_{23}, \ldots, \Lambda_{(n-1)n}$

The thermal conductances $\Lambda_{12}, \Lambda_{23}, \ldots, \Lambda_{(n-1)n}$ shall be determined by iteration of the calculation procedure according to Clause 7 of ISO 10292:1994.

The calculation of the direct solar absorptances $\alpha_{\mathrm{e}1}, \alpha_{\mathrm{e}2}, \ldots, \alpha_{\mathrm{e}n}$ shall be performed using the methods given in 3.5.6.3.

As an example for the calculation of the direct solar absorptances the following procedure is given which consist of the following (n – 1) steps for a glazing consisting of n components.

a) First step: calculate the spectral characteristics of a unit consisting of the (n – 1) components 2, 3, ... , n according to what has been prescribed in 3.3 and 3.4.1. Then combine this unit with the first (outer) pane as a double glazing. $\alpha_{\mathrm{e}1}$ is obtained according to Equation (17).

b) Second step: calculate the spectral characteristics of a unit consisting of the (n – 2) components 3, ... , n and, furthermore, those of a double glazing consisting of pane 1 and pane 2. These units are then combined as a double glazing. The sum $\alpha_{\mathrm{e}1} + \alpha_{\mathrm{e}2}$ is then obtained for this double glazing according to Equation (17), i.e. with the known value of $\alpha_{\mathrm{e}1}$ from the first step, $\alpha_{\mathrm{e}2}$ is obtained. This procedure is continued up to the last (n – 1)th step.

c) (n – 1)th step: combine the (n – 1) panes 1, 2, ... , (n – 1) and determine the spectral characteristics of this unit. This unit is then combined with the nth (inner) pane as a double glazing. From Equation (17) the sum $\alpha_{\mathrm{e}1}, \alpha_{\mathrm{e}2}, \ldots, \alpha_{\mathrm{e}(n-1)}$ is obtained, i.e. with the known values $\alpha_{\mathrm{e}1}, \alpha_{\mathrm{e}2}, \ldots, \alpha_{\mathrm{e}(n-2)}$ from the previous steps $\alpha_{\mathrm{e}(n-1)}$ is determined. $\alpha_{\mathrm{e}n}$ is obtained according to Equation (18).

In the case of triple glazing for the solar absorbtances α_{e1}, α_{e2} and α_{e3} as a function of the spectral characteristics of the individual components of the unit, the following formulae are obtained:

$$\alpha_{e1} = \frac{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \left\{ \alpha_1(\lambda) + \frac{\tau_1(\lambda)\,\alpha'_1(\lambda)\,\rho_2(\lambda)\left[1-\rho'_2(\lambda)\,\rho_3(\lambda)\right] + \tau_1(\lambda)\,\tau_2^2(\lambda)\,\alpha'_1(\lambda)\,\rho_3(\lambda)}{\left[1-\rho'_1(\lambda)\,\rho_2(\lambda)\right]\cdot\left[1-\rho'_2(\lambda)\,\rho_3(\lambda)\right] - \tau_2^2(\lambda)\,\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda\,\Delta\lambda}{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\,\Delta\lambda} \tag{23}$$

$$\alpha_{e2} = \frac{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \left\{ \frac{\tau_1(\lambda)\,\alpha_2(\lambda)\left[1-\rho'_2(\lambda)\,\rho_3(\lambda)\right] + \tau_1(\lambda)\,\tau_2(\lambda)\,\alpha'_2(\lambda)\,\rho_3(\lambda)}{\left[1-\rho'_1(\lambda)\,\rho_2(\lambda)\right]\cdot\left[1-\rho'_2(\lambda)\,\rho_3(\lambda)\right] - \tau_2^2(\lambda)\,\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda\,\Delta\lambda}{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\,\Delta\lambda} \tag{24}$$

$$\alpha_{e3} = \frac{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} \left\{ \frac{\tau_1(\lambda)\,\tau_2(\lambda)\,\alpha_3(\lambda)}{\left[1-\rho'_1(\lambda)\,\rho_2(\lambda)\right]\cdot\left[1-\rho'_2(\lambda)\,\rho_3(\lambda)\right] - \tau_2^2(\lambda)\,\rho'_1(\lambda)\,\rho_3(\lambda)} \right\} S_\lambda\,\Delta\lambda}{\sum\limits_{\lambda = 300\ \text{nm}}^{2\,500\ \text{nm}} S_\lambda\,\Delta\lambda} \tag{25}$$

where

$\tau_1(\lambda)$, $\tau_2(\lambda)$, $\tau_3(\lambda)$, $\rho_1(\lambda)$, $\rho'_1(\lambda)$, $\rho_2(\lambda)$, $\rho'_2(\lambda)$, $\rho_3(\lambda)$ are as defined in 3.3;

$\alpha_1(\lambda)$, $\alpha'_1(\lambda)$ and $\alpha_2(\lambda)$ are as defined in 3.5.6.3.

$\alpha'_2(\lambda)$ is the spectral direct absorptance of the second pane, measured in the opposite direction to the incident radiation, given by the relationship

$$\alpha'_2(\lambda) = 1 - \tau_2(\lambda) - \rho'_2(\lambda) \tag{26}$$

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

$$\alpha_3(\lambda) = 1 - \tau_3(\lambda) - \rho_3(\lambda) \tag{27}$$

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 2. For a glazing with more than three components, the formulae for the solar absorptances α_{e1}, α_{e2}, ... , α_{en} as a function of the individual components become very complex and therefore are not given here.

3.5.7 Total solar energy transmission

The total solar energy transmitted into the room per unit area of glazing ϕ_{ei} is given by the relationship

$$\phi_{ei} = \phi_e\, g \tag{28}$$

where

ϕ_e is the incident solar radiation flux per unit area;

g is the total solar energy transmittance of the glazing.

ϕ_e values can be obtained from appropriate tables in meteorological literature.

3.5.8 Additional heat transfer

If the room temperature T_i differs from the outside temperature T_o, an additional heat transfer occurs in addition to ϕ_{ei}. This additional heat flow q_z can be calculated as follows:

$$q_z = U(T_o - T_i) \tag{29}$$

where U is the U value (thermal transmittance) of glazing, determined according to ISO 10291, ISO 10292 or ISO 10293.

3.6 UV-transmittance

The UV-transmittance of glazing is the fraction of the incident solar radiation transmitted by the glazing in the 300 nm to 380 nm range (UV-B range from 300 nm to 315 nm and UV-A range from 315 nm to 380 nm). The relative spectral distribution, S_λ, used to calculate the UV-transmittance is derived from the global solar irradiance given in ISO 9845-1:1992, Table 1, column 5; i.e. it corresponds to the global irradiance specified for the calculation of the solar direct transmittance (see 3.5.3). Table 3 gives the values of $S_\lambda \, \Delta\lambda$ for wavelength intervals of 5 nm in the UV range. This table has been drawn up with relative values in such a way that $\Sigma S_\lambda \Delta\lambda = 1$ for the total UV range.

The UV-transmittance τ_{UV} is calculated as follows:

$$\tau_{UV} = \frac{\sum_{\lambda = 300\text{ nm}}^{380\text{ nm}} \tau(\lambda)\, S_\lambda \, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{380\text{ nm}} S_\lambda \, \Delta\lambda} \tag{30}$$

where

S_λ is the relative spectral distribution of UV-radiation;

$\tau(\lambda)$ is the spectral transmittance of the glazing (see 3.3);

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelength given in Table 3.

This average extends over the defined UV-portion of the solar spectrum. It may not be correlated with solar radiation damage of materials and skin.

3.7 CIE damage factor

The CIE damage factor τ_{df} (see reference [6]) is calculated according to the following formulae:

$$\tau_{df} = \frac{\sum_{\lambda = 300\text{ nm}}^{600\text{ nm}} \tau(\lambda)\, C_\lambda \, S_\lambda \, \Delta\lambda}{\sum_{\lambda = 300\text{ nm}}^{600\text{ nm}} C_\lambda \, S_\lambda \, \Delta\lambda} \tag{31}$$

$$C_\lambda = \mathrm{e}^{-0{,}012\,\lambda} \text{ (with } \lambda \text{ in nanometres)} \tag{32}$$

where

S_λ is the relative spectral distribution of solar radiation;

$\tau(\lambda)$ is the spectral transmittance of the glazing (see 3.3);

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 4.

Table 4 gives the values of $C_\lambda S_\lambda \, \Delta\lambda$. This table has been drawn up with relative values in such a way that $\Sigma C_\lambda S_\lambda \Delta\lambda = 1$ for the range from 300 nm to 600 nm.

This average extends over the UV and part of the visible portions of the solar spectrum, which may contribute to the solar radiation damage of materials.

3.8 Skin damage factor

The skin damage factor F_{sd} (see reference [7]) is calculated according to the following formula:

$$F_{\text{sd}} = \frac{\sum\limits_{\lambda = 300\text{ nm}}^{400\text{ nm}} \tau(\lambda)\, E_\lambda \, S_\lambda \, \Delta\lambda}{\sum\limits_{\lambda = 300\text{ nm}}^{400\text{ nm}} E_\lambda \, S_\lambda \, \Delta\lambda} \tag{33}$$

where

S_λ is the relative spectral distribution of solar radiation;

E_λ is the CIE erythemal effectiveness spectrum;

$\tau(\lambda)$ is the spectral transmittance of the glazing (see 3.3);

$\Delta\lambda$ and the integration procedure are the same as in 3.3 except that the data points shall be chosen at the wavelengths given in Table 5.

Table 5 gives the values of $E_\lambda S_\lambda \, \Delta\lambda$. This table has been drawn up with relative values in such a way that $\Sigma E_\lambda S_\lambda \, \Delta\lambda = 1$ for the range from 300 nm to 400 nm.

This average extends over the UV and part of the visible portions of the solar spectrum, which may contribute to the solar radiation damage of skin.

3.9 Colour rendering

The colour-rendering properties of the transmitted light are given by the general colour rendering index R_{a}. R_{a} shall be calculated according to the test colour method which has been established by the International Commission on Illumination (CIE) as the recommended method for specifying colour-rendering properties of light sources, and which also may be used for specifying modifications of daylight (see CIE 13.3).

To determine the general colour-rendering index of glazing in transmittance R_{a}, illuminant D65 shall be used as the reference light source and the relative spectral distribution $D_\lambda \tau(\lambda)$ corresponds to the light source whose general colour rendering index R_{a} is to be determined.

In the preceding text:

D_λ is the spectral power distribution of D65 (see ISO/CIE 10526);

$\tau(\lambda)$ is the spectral transmittance of glazing (see 3.3).

The reference illuminant D65 shall be indicated in brackets after the rating figure [e.g. $R_\mathrm{a} = 90$ (D65)].

R_a may reach a maximum value of 100. This will be achieved for glazing whose spectral transmittance is completely constant in the visible spectral range. In the technique of illumination, general colour-rendering indices $R_\mathrm{a} > 90$ characterize a very good and values $R_\mathrm{a} > 80$ a good colour rendering.

4 Reference values

The characteristics of this International Standard shall be determined according to the specifications fixed in 3.5.6.1 They represent well-defined average boundary conditions. In this way basic information on the performance of glazing is obtained and an appropriate comparison of different products in technical information can be achieved.

To meet special local and product requirements, the characteristics of this International Standard may also be determined for the following different boundary conditions:

- the standardized values for the heat transfer coefficients to the outside and the inside (see 3.5.6.1) may be replaced by other values;
- for the determination of the thermal conductance(s) Λ (see 3.5.6.3 and 3.5.6.4), the standardized values (i.e. a mean sample temperature of 10 °C and a temperature difference $\Delta T = 15$ °C across the sample) may be substituted by other values.

If the specified standard conditions prescribed in 3.5.6.1 are varied as allowed above, the test report shall mention what standard conditions have been changed and shall detail the variations.

5 Test report

The test report shall state the following:

- the results for the required characteristics;
- the number and thickness of panes in the glazing;
- the type and position of panes (for the case of multiple glazing), designated as outer pane, second pane, etc.;
- the position of coating(s) (for the case of coated glass) designating the faces of the panes as 1, 2, 3, etc., starting from the outer surface of the outer pane;
- the type of instrument used for the optical measurements (specifying, if used, the reflectance accessory or integrating sphere and reference materials for reflectance);
- specification of boundary conditions if different from standardized values (see Clause 4).

The general colour rendering index R_a shall be given to two significant numbers; all other characteristics to two decimal places.

Table 1 — Normalized relative spectral distribution $D_\lambda V(\lambda)\Delta\lambda$

λ nm	$D_\lambda\ V(\lambda)\Delta\lambda \times 10^2$	λ nm	$D_\lambda\ V(\lambda)\Delta\lambda \times 10^2$
380	0	600	5,354 2
390	0,000 5	610	4,249 1
400	0,003 0	620	3,150 2
410	0,010 3	630	2,081 2
420	0,035 2	640	1,381 0
430	0,094 8	650	0,807 0
440	0,227 4	660	0,461 2
450	0,419 2	670	0,248 5
460	0,666 3	680	0,125 5
470	0,985 0	690	0,053 6
480	1,518 9	700	0,027 6
490	2,133 6	710	0,014 6
500	3,349 1	720	0,005 7
510	5,139 3	730	0,003 5
520	7,052 3	740	0,002 1
530	8,799 0	750	0,000 8
540	9,442 7	760	0,000 1
550	9,807 7	770	0,000 0
560	9,430 6	780	0,000 0
570	8,689 1		
580	7,899 4		
590	6,330 6		

Normalized relative spectral distribution D_λ of illuminant D65 multiplied by the spectral luminous efficiency $V(\lambda)$ and by the wavelength interval $\Delta\lambda$. The values in this table are calculated according to the trapezoidal rule.

Table 2 — Normalized relative spectral distribution of global solar radiation

λ nm	$S_\lambda \Delta\lambda$	λ nm	$S_\lambda \Delta\lambda$
300	0	680	0,012 838
305	0,000 057	690	0,011 788
310	0,000 236	700	0,012 453
315	0,000 554	710	0,012 798
320	0,000 916	720	0,010 589
325	0,001 309	730	0,011 233
330	0,001 914	740	0,012 175
335	0,002 018	750	0,012 181
340	0,002 189	760	0,009 515
345	0,002 260	770	0,010 479
350	0,002 445	780	0,011 381
355	0,002 555	790	0,011 262
360	0,002 683	800	0,028 718
365	0,003 020	850	0,048 240
370	0,003 359	900	0,040 297
375	0,003 509	950	0,021 384
380	0,003 600	1 000	0,036 097
385	0,003 529	1 050	0,034 110
390	0,003 551	1 100	0,018 861
395	0,004 294	1 150	0,013 228
400	0,007 812	1 200	0,022 551
410	0,011 638	1 250	0,023 376
420	0,011 877	1 300	0,017 756
430	0,011 347	1 350	0,003 743
440	0,013 246	1 400	0,000 741
450	0,015 343	1 450	0,003 792
460	0,016 166	1 500	0,009 693
470	0,016 178	1 550	0,013 693
480	0,016 402	1 600	0,012 203
490	0,015 794	1 650	0,010 615
500	0,015 801	1 700	0,007 256
510	0,015 973	1 750	0,007 183
520	0,015 357	1 800	0,002 157
530	0,015 867	1 850	0,000 398
540	0,015 827	1 900	0,000 082
550	0,015 844	1 950	0,001 087
560	0,015 590	2 000	0,003 024
570	0,015 256	2 050	0,003 988
580	0,014 745	2 100	0,004 229
590	0,014 330	2 150	0,004 142
600	0,014 663	2 200	0,003 690
610	0,015 030	2 250	0,003 592
620	0,014 859	2 300	0,003 436
630	0,014 622	2 350	0,003 163
640	0,014526	2 400	0,002 233
650	0,014 445	2 450	0,001 202
660	0,014 313	2 500	0,000 475
670	0,014 023		

Normalized relative spectral distribution of global solar radiation (direct + diffuse) S_λ for air mass = 1,5, calculated from the values given in Table 1, column 5, of ISO 9845-1:1992, multiplied by the wavelength interval $\Delta\lambda$. The values in this table are calculated according to the trapezoidal rule.

Table 3 — Normalized relative spectral distribution of the UV part of global solar radiation

λ nm	$S_\lambda \Delta\lambda$
300	0
305	0,001 859
310	0,007 665
315	0,017 961
320	0,029 732
325	0,042 466
330	0,062 108
335	0,065 462
340	0,071 020
345	0,073 326
350	0,079 330
355	0,082 894
360	0,087 039
365	0,097 963
370	0,108 987
375	0,113 837
380	0,058 351

Normalized relative spectral distribution of the UV part of global solar radiation (direct + diffuse) S_λ for air mass = 1,5, calculated from the values given in Table 1, column 5, of ISO 9845-1:1992, multiplied by the wavelength interval $\Delta\lambda$. The values in this table are calculated according to the trapezoidal rule.

Table 4 — Normalized relative spectral distribution factors for the calculation of the CIE damage factor

λ nm	$C_\lambda S_\lambda \Delta\lambda$
300	0
305	0,001 003
310	0,003 896
315	0,008 597
320	0,013 402
325	0,018 028
330	0,024 831
335	0,024 648
340	0,025 183
345	0,024 487
350	0,024 949
355	0,024 551
360	0,024 278
365	0,025 734
370	0,026 962
375	0,026 522
380	0,025 624
385	0,023 656
390	0,022 418
395	0,025 529
400	0,043 742
410	0,057 799
420	0,052 317
430	0,044 328
440	0,045 896
450	0,047 150
460	0,044 062
470	0,039 108
480	0,035 167
490	0,030 034
500	0,026 650
510	0,023 893
520	0,020 373
530	0,018 671
540	0,016 517
550	0,014 665
560	0,012 799
570	0,011 108
580	0,009 522
590	0,008 208
600	0,003 695

Normalized relative spectral distribution of the UV and part of visible portions of global solar radiation (direct + diffuse) S_λ for air mass = 1,5, calculated from the values given in Table 1, column 5, of ISO 9845-1:1992, multiplied by the wavelength interval $\Delta\lambda$, and by the CIE damage factor (see reference [6]). The values in the table are calculated according to the trapezoidal rule.

Table 5 — Normalized relative spectral distribution factors for the calculation of the skin damage factor

λ nm	$E_\lambda S_\lambda \Delta\lambda$
300	0
305	0,168 176
310	0,230 555
315	0,187 429
320	0,102 699
325	0,050 895
330	0,034 134
335	0,030 432
340	0,027 729
345	0,024 094
350	0,021 930
355	0,019 298
360	0,017 028
365	0,016 157
370	0,015 108
375	0,013 298
380	0,011 471
385	0,009 440
390	0,008 009
395	0,008 165
400	0,003 953
Normalized relative spectral distribution of the UV and part of visible portions of global solar radiation (direct + diffuse) S_λ for air mass = 1,5, calculated from the values given in Table 1, column 5, of ISO 9845-1:1992, multiplied by the wavelength interval $\Delta\lambda$, and by the CIE erythemal effectiveness spectrum (see reference [7]). The values in the table are calculated according to the trapezoidal rule.	

Annex A
(normative)

Calculation procedures

A.1 Procedures for the calculation of the spectral transmittance and reflectance of an uncoated glass plate with thickness y from its spectral transmittance measured for the thickness x

If the spectral transmittance $\tau_x(\lambda)$ of a glass plate with thickness x is known, and also the refractive index of the glass, $\eta(\lambda)$ (for soda lime glass see reference [8]), then the spectral transmittance for thickness y is calculated using the formula:

$$\tau_y(\lambda) = \frac{\left[1 - \rho_\mathrm{s}(\lambda)\right]^2 \tau_{\mathrm{i},y}(\lambda)}{1 - \rho_\mathrm{s}^2(\lambda)\,\tau_{\mathrm{i},y}^2(\lambda)} \tag{A.1}$$

where

$\rho_\mathrm{s}(\lambda)$ designates reflectance at the air-glass interface according to the following formula:

$$\rho_\mathrm{s}(\lambda) = \left[\frac{\eta(\lambda) - 1}{\eta(\lambda) + 1}\right]^2 \tag{A.2}$$

and

$\tau_{\mathrm{i},y}(\lambda)$ designates the internal transmittance of a glass plate with a thickness y according to the following formula:

$$\tau_{\mathrm{i},y}(\lambda) = \left[\tau_{\mathrm{i},x}(\lambda)\right]^{y/x} \tag{A.3}$$

$\tau_{\mathrm{i},x}(\lambda)$ designates the internal transmittance of a glass plate with a thickness x, determined from its measured spectral transmittance according to the following formula:

$$\tau_{\mathrm{i},x}(\lambda) = \frac{\left[\left[1 - \rho_\mathrm{s}(\lambda)\right]^4 + 4\rho_\mathrm{s}^2(\lambda)\,\tau_x^2(\lambda)\right]^{1/2} - \left[1 - \rho_\mathrm{s}(\lambda)\right]^2}{2\rho_\mathrm{s}^2(\lambda)\,\tau_x(\lambda)} \tag{A.4}$$

In a similar way the spectral reflectance is calculated for a thickness y according to the following formula:

$$\rho_y(\lambda) = \rho_\mathrm{s}(\lambda)\left\{1 + \frac{\left[1 - \rho_\mathrm{s}(\lambda)\right]^2 \tau_{\mathrm{i},y}^2(\lambda)}{1 - \rho_\mathrm{s}^2(\lambda)\,\tau_{\mathrm{i},y}^2(\lambda)}\right\} \tag{A.5}$$

EXAMPLE

A green glass plate is 3,0 mm thick. At 550 nm the measured spectral transmittance is 0,83 and its refractive index is 1,525. Calculate the transmittance of the same glass for a thickness of 5 mm.

SOLUTION

$x = 3{,}00$

$\tau_x = 0{,}83$

$\eta = 1{,}525$

$y = 5{,}00$

Equation (A.2) gives	$\rho_\mathrm{s} = 0{,}043\,2$
Equation (A.4) gives	$\tau_{\mathrm{i},x} = 0{,}905\,3$
Equation (A.3) gives	$\tau_{\mathrm{i},y} = 0{,}847\,2$
Equation (A.1) gives	$\tau_y = 0{,}776\,6$, rounded to 0,78
Equation (A.5) gives	$\rho_y = 0{,}071\,7$, rounded to 0,07

A.2 Procedures for the calculation of the spectral transmittance and reflectance of a coated glass plate with thickness y from the spectral transmittance and reflectance of a plate of a different glass with thickness x on which the same coating with the same thickness has been deposited

A.2.1 In the equations reported below, it is convenient to use the following symbols to designate the intrinsic photometric characteristics of the coating in the air-coating-glass system (see Figure A.1):

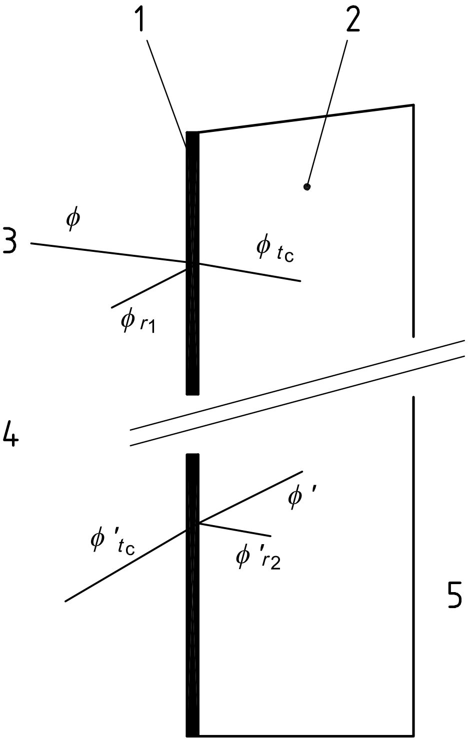
$r_1(\lambda)$	spectral reflectance of the coating for light incident from the air towards the coating;
$r_2(\lambda)$	spectral reflectance of the coating for light incident from the glass towards the coating;
$t_\mathrm{c}(\lambda)$	spectral transmittance of the system: air-coating-substrate.

The values of such characteristics are calculated from the measured spectral characteristics $[\rho_\mathrm{s}(\lambda), \tau_\mathrm{i}(\lambda)]$ of a sample of previously characterized glass on which the coating has been deposited and from the following measured characteristics:

— $\rho_1(\lambda)$: spectral reflectance of the coated glass, measured in the direction air-coating-glass;

— $\rho_2(\lambda)$: spectral reflectance of the coated glass, measured in the direction air-glass-coating;

— $\tau(\lambda)$: spectral transmittance of the coated glass.



Key

1 coating
2 glass plate
3 air-coating direction
4 air
5 glass-coating-air direction

Figure A.1 — Illustration of the meaning of r_1, r_2 and t_c

The following equations are applied:

$$r_1(\lambda) = \rho_1(\lambda) - \frac{\rho_s(\lambda)\,\tau^2(\lambda)}{D(\lambda)} \tag{A.6}$$

$$r_2(\lambda) = \frac{\rho_2(\lambda) - \rho_s(\lambda)}{D(\lambda)\,\tau_i^2(\lambda)} \tag{A.7}$$

$$t_c(\lambda) = \frac{\tau(\lambda)\left[1 - \rho_s(\lambda)\right]}{D(\lambda)\,\tau_i(\lambda)} \tag{A.8}$$

where

$$D(\lambda) = \rho_s(\lambda)\left[\rho_2(\lambda) - \rho_s(\lambda)\right] + \left[1 - \rho_s(\lambda)\right]^2 \tag{A.9}$$

$\rho_s(\lambda)$ and $\tau_i(\lambda)$, characterizing the original glass, are as defined in A.1.

A.2.2 From such intrinsic characteristics of the system air-coating-glass, the spectral characteristics of another coated glass consisting of the same coating deposited on a plate of a different glass, assumed to have the same refractive index, can be calculated (see reference [8]).

The following equations are valid:

$$\rho_1(\lambda) = r_1(\lambda) + \frac{\rho_s(\lambda)\, t_c^2(\lambda)\, \tau_i^2(\lambda)}{D'(\lambda)} \qquad \text{(A.10)}$$

$$\rho_2(\lambda) = \rho_s(\lambda) + \frac{r_2(\lambda)\left[1-\rho_s(\lambda)\right]^2 \tau_i^2(\lambda)}{D'(\lambda)} \qquad \text{(A.11)}$$

$$\tau(\lambda) = \frac{\left[1-\rho_s(\lambda)\right] \tau_i(\lambda)\, t_c(\lambda)}{D'(\lambda)} \qquad \text{(A.12)}$$

where

$$D'(\lambda) = 1 - \rho_s(\lambda)\, r_2(\lambda)\, \tau_i^2(\lambda) \qquad \text{(A.13)}$$

$\tau_i(\lambda)$ and $\rho_s(\lambda)$ are, respectively, the internal transmittance and the air-glass reflectance of the other coated glass.

EXAMPLE

A reflective coating is deposited on a clear glass 6,00 mm thick. At the wavelength of 550 nm the optical characteristics of such coated glass are the following:

- transmittance $\tau = 0{,}377$;
- reflectance measured on the coated side: $\rho_1 = 0{,}345$;
- reflectance measured on the uncoated side: $\rho_2 = 0{,}283$.

What are the characteristics of a coated glass consisting of the same coating deposited on a green glass 4 mm thick?

It is assumed that the clear and the green glass have the same index of refraction, i.e. $\eta = 1{,}525$.

SOLUTION

Before applying Equations (A.6) to (A.9), it is necessary to calculate the internal transmittance, τ_i, of the clear glass of 6,00 mm thickness.

Knowing that the clear glass has a transmittance $\tau_x = 0{,}894$, for a thickness $x = 6{,}00$ mm, by applying Equations (A.2) and (A.4), the following values are obtained:

$\tau_i = 0{,}974\,9$ for a clear glass of 6,00 mm thickness;

Equation (A.9) gives $D = 0{,}925\,8$;

Equation (A.6) gives $r_1 = 0{,}338\,4$;

Equation (A.7) gives $r_2 = 0{,}272\,5$;

Equation (A.8) gives $t_c = 0{,}399\,7$.

The application of Equations (A.10) to (A.13) requires knowledge of the internal transmittance of the green glass for a thickness of 4 mm.

The example described in A.1 leads to such a value by applying Equation (A.3):

$$\tau_1 = (0{,}905\,3)^{4/3} = 0{,}875\,8$$

Equation (A.13) gives $D' = 0{,}991\,0$;

Equation (A.10) gives $\rho_1 = 0{,}343\,7$, rounded to 0,34;

Equation (A.11) gives $\rho_2 = 0{,}236\,3$, rounded to 0,24;

Equation (A.12) gives $\tau = 0{,}337\,9$, rounded to 0,34.

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