BSI Standards Publication

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

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National foreword

This British Standard is the UK implementation of EN 410:2011. It supersedes BS EN 410:1998 which is withdrawn.

The UK participation in its preparation was entrusted to Technical Committee B/520/4, Properties and glazing methods.

A list of organizations represented on this committee can be obtained on request to its secretary.

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English Version

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

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

Glas im Bauwesen - Bestimmung der lichttechnischen und strahlungsphysikalischen Kenngrößen von Verglasungen

This European Standard was approved by CEN on 2 January 2011.

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Foreword

This document (EN 410:2011) has been prepared by Technical Committee CEN/TC 129 “Glass in building”, the secretariat of which is held by NBN.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by August 2011, and conflicting national standards shall be withdrawn at the latest by August 2011.

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

This document supersedes EN 410:1998.

The main changes compared to the previous edition are:

a) A procedure is provided for the calculation of the spectral properties of laminated glass.

b) A formula is introduced for determining the total shading coefficient.

c) Table 3 has been updated to make it more practical.

d) Table 6 has been updated in line with the 2004 edition of the publication CIE No 15.

e) The external and internal heat transfer coefficients have been amended slightly to reflect changes to EN 673.

f) Guidance is also given on how to determine the spectral characteristics of screen printed glass.

g) New drawings have been introduced for improved clarity and to conform with CEN rules.

This document has been prepared under a mandate given to CEN by the European Commission and the European Free Trade Association, and supports essential requirements of EU Directive(s).

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Norway, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, Switzerland and United Kingdom.

Introduction

While this European Standard 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 are required to determine the spectral parameters, the uncertainty is cumulative with the number of measurements and should be considered in the final results.

The term interface used in this European Standard, is considered to be 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 European Standard), 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).

1 Scope

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

This European Standard 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.

This European Standard 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 5.2).

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

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.

EN 673, *Glass in building — Determination of thermal transmittance (U value) — Calculation method*

EN 674, *Glass in building — Determination of thermal transmittance (U value) — Guarded hot plate method*

EN 675, *Glass in building — Determination of thermal transmittance (U value) — Heat flow meter method*

EN 12898, *Glass in building — Determination of the emissivity*

3 Terms and definitions

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

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 (solar factor)
fraction of the incident solar radiation that is totally transmitted by the glass

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

3.5
normal emissivity
ratio, in a direction normal to the surface, of the emissive power of the surface of the glass to the emissive power of a black body

NOTE Normal emissivity is determined in accordance with EN 12898.

3.6
solar direct reflectance
fraction of the incident solar radiation that is reflected by the glass

3.7
ultraviolet transmittance
fraction of the incident UV component of the solar radiation that is transmitted by the glass

3.8
colour rendering index (in transmission)
change in colour of an object as a result of the light being transmitted by the glass

3.9
shading coefficient
ratio of the solar factor of the glass to the solar factor of a reference glass (clear float)

4 Symbols

Sym.	Deutsch/German/Allemand	Englisch/English/Anglais	Französisch/French/Français
D65	Normlichtart D65	standard illuminant D65	illuminant normalisé D65
UV	Ultravioletter Strahlungsbereich	ultraviolet radiation	rayonnement ultraviolet
τ_{UV}	Ultravioletter Transmissionsgrad	ultraviolet transmittance	facteur de transmission de l'ultraviolet
$\tau(\lambda)$	Spektraler Transmissionsgrad	spectral transmittance	facteur de transmission spectrale
$\rho(\lambda)$	Spektraler Reflexionsgrad	spectral reflectance	facteur de réflexion spectrale
τ_{v}	Lichtransmissionsgrad	light transmittance	facteur de transmission lumineuse
ρ_{v}	Lichtreflexionsgrad	light reflectance	facteur de réflexion lumineuse
τ_{e}	direkter Strahlungstransmissionsgrad	solar direct transmittance	facteur de transmission directe de l'énergie solaire
ρ_{e}	direkter Strahlungsreflexionsgrad	solar direct reflectance	facteur de réflexion directe de l'énergie solaire

g	Gesamtenergiedurchlaß- grad	total solar energy transmittance (solar factor)	facteur de transmission totale de l'énergie solaire ou facteur solaire
R_a	allgemeiner Farbwiedergabeindex	general colour rendering index	indice général de rendu des couleurs
D_λ	relative spektrale Vertei- lung der Normlichtart D65	relative spectral distribution of illuminant D65	répartition spectrale relative de l'illuminant normalisé D65
$V(\lambda)$	spektraler Hellempfindlichkeitsgrad	spectral luminous efficiency	efficacité lumineuse relative spectrale
α_e	direkter Strahlungsabsorp tionsgrad	solar direct absorptance	facteur d'absorption directe de l'énergie solaire
ϕ_e	Strahlungsleistung (Strahlungsfluß)	incident solar radiant flux	flux énergétique solaire incident
q_i	sekundärer Wärmeabgabegrad nach innen	secondary internal heat transfer factor	facteur de réémission thermique vers l'intérieur
q_e	sekundärer Wärmeabgabegrad nach außen	secondary external heat transfer factor	facteur de réémission thermique vers l'extérieur
S_λ	relative spektrale Vertei- lung der Sonnenstrahlung	relative spectral distribution of solar radiation	répartition spectrale relative du rayonnement solaire
h_e	Wärmeübergangs- koeffizient nach außen	external heat transfer coefficient	coefficient d'échange thermique extérieur
h_i	Wärmeübergangs- koeffizient nach innen	internal heat transfer coefficient	coefficient d'échange thermique intérieur
ε	korrigierter Emissionsgrad	corrected emissivity	émissivité corrigée
ε_n	normaler Emissionsgrad	normal emissivity	émissivité normale
Λ	Wärmedurchlaßkoeffizient	thermal conductance	conductance thermique
λ	Wellenlänge	wavelength	longueur d'onde
$\Delta\lambda$	Wellenlängenintervall	wavelength interval	intervalle de longueur d'onde
U_λ	relative spektrale Vertei- Lung der UV-Strahlung der Sonne	relative spectral distribution of UV in solar radiation	répartition spectrale relative du rayonnement ultraviolet solaire
SC	Durchlassfaktor	shading coefficient	coefficient d’ombrage

5 Determination of characteristics

5.1 General

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

The characteristics are as follows:

- the spectral transmittance $\tau(\lambda)$ and the spectral reflectance $\rho(\lambda)$ in the wavelength range from 300 nm to 2500 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 (solar factor) g ;
- the UV-transmittance τ_{UV};
- the general colour rendering index R_a;
- the total shading coefficient, SC.

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 required for different glass thicknesses (in the case of uncoated glass) or for the same coating applied to different substrates, it can 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.

5.2 Light transmittance

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

$$\tau_v = \frac{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda \tau(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380\text{ nm}}^{780\text{ nm}} D_\lambda V(\lambda) \Delta\lambda} \qquad (1)$$

where

D_λ is the relative spectral distribution of illuminant D65 (see Bibliography [5]);

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

$V(\lambda)$ is the spectral luminous efficiency for photopic vision defining the standard observer for photometry (see Bibliography [5]);

$\Delta\lambda$ is the wavelength interval.

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

In the case of multiple glazing, the spectral transmittances $\tau(\lambda)$ are calculated from the spectral transmittances and reflectances of the individual components as follows :

For double glazing:

$$\tau(\lambda) = \frac{\tau_1(\lambda)\, \tau_2(\lambda)}{1 - \rho_1'(\lambda)\, \rho_2(\lambda)} \tag{2}$$

where

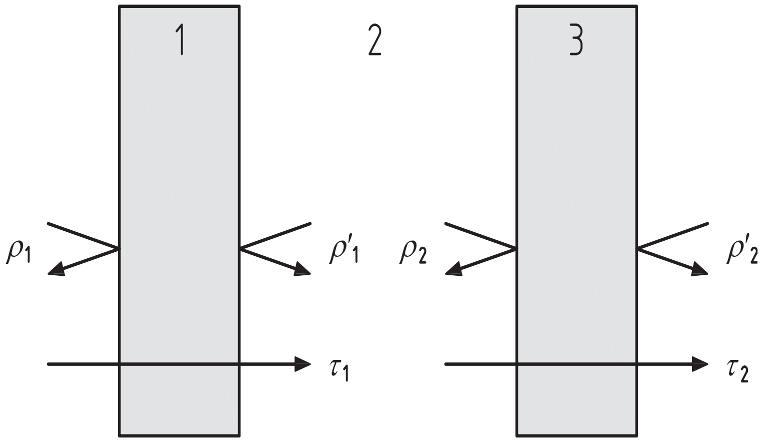
$\tau_1(\lambda)$ is the spectral transmittance of the first (outer) pane;

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

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

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

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:

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

where

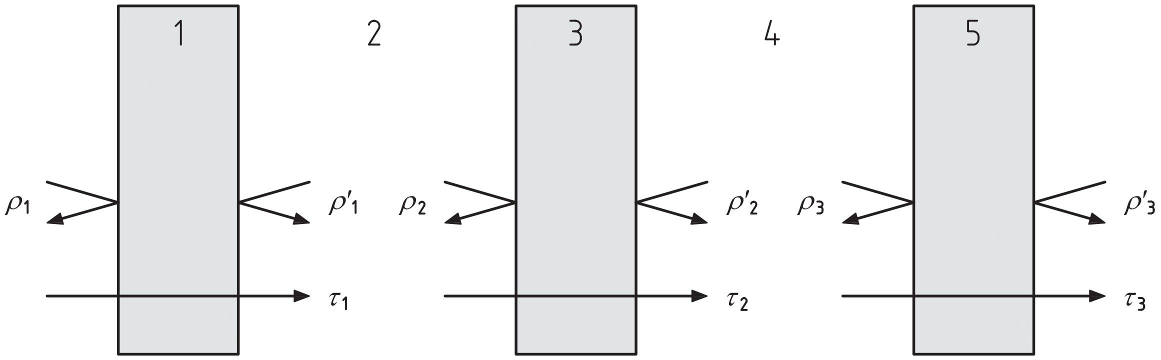
$\tau_1(\lambda)$, $\tau_2(\lambda)$, $\rho'_1(\lambda)$ and $\rho_2(\lambda)$ are as explained in Equation (2);

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

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

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

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 Equations (2) and (3) 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.

NOTE 1 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 shall be large enough to collect all possible scattered light and to obtain fair average values when surface patterns are irregularly distributed.

NOTE 2 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 reflectance

The light reflectance of the glazing ρ_v is calculated using the following formula:

$$\rho_v = \frac{\sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda \rho(\lambda) V(\lambda) \Delta\lambda}{\sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} D_\lambda V(\lambda) \Delta\lambda} \tag{4}$$

where

D_λ, $V(\lambda)$ and $\Delta\lambda$ are as explained in 5.2;

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

In the case of multiple glazing, the spectral reflectance $\rho(\lambda)$ is calculated from the spectral transmittances and the spectral reflectances of the individual components as follows.

For double glazing, the external light reflectance of the glazing is calculated as follows:

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

where

$\tau_1(\lambda)$, $\rho_2(\lambda)$ and $\rho_1'(\lambda)$ are as explained in 5.2;

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

A corresponding equation can also be derived for calculating the internal light reflectance.

For triple glazing, the external light reflectance of the glazing is calculated as follows:

$$\rho(\lambda) = \rho_1(\lambda) + \frac{\tau_1^2(\lambda)\,\rho_2(\lambda)\,[1 - \rho_2'(\lambda)\,\rho_3(\lambda)] + \tau_1^2(\lambda)\,\tau_2^2(\lambda)\,\rho_3(\lambda)}{[1 - \rho_1'(\lambda)\,\rho_2(\lambda)]\,[1 - \rho_2'(\lambda)\,\rho_3(\lambda)] - \tau_2^2(\lambda)\,\rho_1'(\lambda)\,\rho_3(\lambda)} \tag{6}$$

where

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

$\tau_1(\lambda)$, $\tau_2(\lambda)$, $\rho_1(\lambda)$, $\rho_2(\lambda)$, $\rho_1'(\lambda)$ and $\rho_2'(\lambda)$ are as defined in 5.2 and 5.3.

A corresponding equation the internal light reflectance of triple glazing can also be derived.

For glazing with more than three elements the same method as described in 5.2 is used.

5.4 Total solar energy transmittance (solar factor)

5.4.1 Calculation

The total solar energy transmittance g is calculated as the sum of the solar direct transmittance τ_e and the secondary heat transfer factor q_i of the glazing towards the inside (see 5.4.3 and 5.4.6), 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:

$$g = \tau_\mathrm{e} + q_i \tag{7}$$

5.4.2 Division of incident solar radiant flux

The incident solar radiant flux ϕ_e is divided into the following three parts (see Figure 3):

a) the transmitted part, $\tau_\mathrm{e}\phi_\mathrm{e}$;

b) the reflected part, $\rho_\mathrm{e}\phi_\mathrm{e}$;

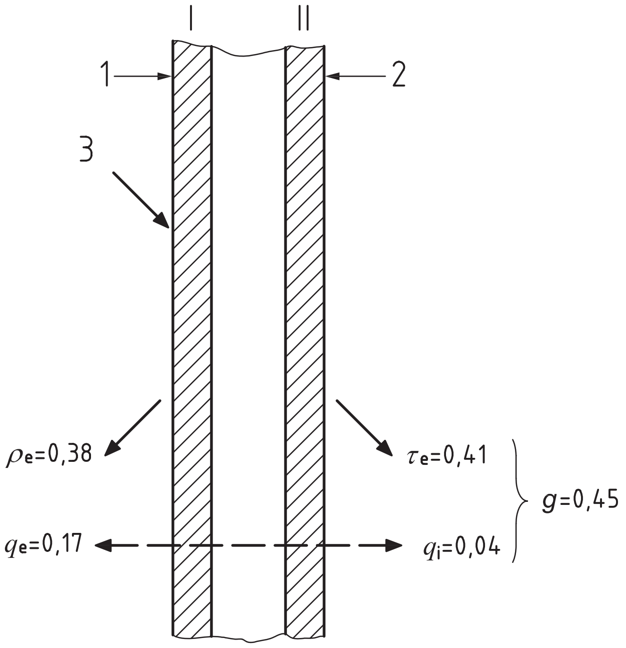
c) the absorbed part, $\alpha_\mathrm{e}\phi_\mathrm{e}$;

where

τ_e is the solar direct transmittance (see 5.4.3);

ρ_e is the solar direct reflectance (see 5.4.4);

α_e is the solar direct absorptance (see 5.4.5).



Key

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

Figure 3 — Example of division of the incident radiant flux

The relation between the three characteristics is:

$$\tau_e + \rho_e + \alpha_e = 1 \tag{8}$$

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

$$\alpha_e = q_i + q_e \tag{9}$$

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.

5.4.3 Solar direct transmittance

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

$$\tau_e = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \tau(\lambda)\, \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda} \tag{10}$$

where

S_λ is the relative spectral distribution of the solar radiation (see Table 2);

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

$\Delta\lambda$ is the wavelength interval.

In the case of multiple glazing, the spectral transmittance $\tau(\lambda)$ is calculated in accordance with 5.2.

The relative spectral distribution, S_λ, used to calculate the solar direct transmittance is derived from CIE 85 [6].

The corresponding values $S_\lambda \Delta\lambda$ are given in Table 2. The table was drawn up in such a way that $\sum S_\lambda \Delta\lambda = 1$.

NOTE Contrary to real situations, it is always assumed, for simplification, that the spectral distribution of the solar radiation (see Table 2) is not dependent upon atmospheric conditions (e.g. dust, mist, moisture content) and that the solar radiation strikes the glazing as a collimated beam and at normal incidence. The resulting errors are very small.

5.4.4 Solar direct reflectance

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

$$\rho_e = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \rho(\lambda)\, \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda} \tag{11}$$

where

S_λ is the relative spectral distribution of the solar radiation (see Table 2);

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

$\Delta\lambda$ is the wavelength interval.

In the case of multiple glazing, the spectral reflectance $\rho(\lambda)$ is calculated in accordance with 5.3.

5.4.5 Solar direct absorptance

The solar direct absorptance α_e is calculated from Equation (8) in 5.4.2.

5.4.6 Secondary heat transfer factor towards the inside

5.4.6.1 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 standard is to provide basic information on the performance of glazing, conventional conditions have been stated for simplicity:

a) position of the glazing: vertical;

b) outside surface: wind velocity: approximately 4 m/s, corrected emissivity = 0,837;

c) inside surface: natural convection, emissivity optional;

d) air spaces are unventilated.

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

$$h_\mathrm{e} = 25\ W/\left(m^2.K\right)$$

$$h_\mathrm{i} = 3,6 + \frac{4.1\varepsilon_i}{0,837}\ W/\left(m^2.K\right)$$

where

ε_i is the corrected emissivity of the inside surface.

For uncoated soda lime silicate glass and borosilicate glass $\varepsilon_\mathrm{i} = 0,837$ and $h_\mathrm{i} = 7,7\ W/\left(m^2.K\right)$.

The corrected emissivity shall be defined and measured in accordance with EN 12898.

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

5.4.6.2 Single glazing

The secondary internal heat transfer factor, q_i, of single glazing is calculated using the following formula:

$$q_\mathrm{i} = \alpha_\mathrm{e} \frac{h_\mathrm{i}}{h_\mathrm{e} + h_\mathrm{i}} \tag{12}$$

where

α_e is the solar direct absorptance in accordance with 5.4.5;

h_e and h_i are the heat transfer coefficients towards the outside and inside respectively in accordance with 5.4.6.1.

5.4.6.3 Double glazing

The secondary internal heat transfer factor, q_i, of double glazing is calculated using the following formula:

$$q_\mathrm{i} = \frac{\left[\frac{\alpha_{\mathrm{e}1} + \alpha_{\mathrm{e}2}}{h_\mathrm{e}} + \frac{\alpha_{\mathrm{e}2}}{\Lambda}\right]}{\left[\frac{1}{h_\mathrm{i}} + \frac{1}{h_\mathrm{e}} + \frac{1}{\Lambda}\right]} \tag{13}$$

where

h_e and h_i are the heat transfer coefficients towards the outside and inside respectively in accordance with 5.4.6.1;

α_{e1} is the solar direct absorptance of the outer 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 4).

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

$$\alpha_{e1} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \left\{ \alpha_1(\lambda) + \frac{\alpha_1'(\lambda)\tau_1(\lambda)\rho_2(\lambda)}{1-\rho_1'(\lambda)\rho_2(\lambda)} \right\} \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda} \qquad (14)$$

$$\alpha_{e2} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \left\{ \frac{\alpha_2(\lambda)\tau_1(\lambda)}{1-\rho_1'(\lambda)\rho_2(\lambda)} \right\} \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} S_\lambda \Delta\lambda} \qquad (15)$$

where

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

$$\alpha_1(\lambda) = 1 - \tau_1(\lambda) - \rho_1(\lambda) \qquad (16)$$

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

$$\alpha_1'(\lambda) = 1 - \tau_1(\lambda) - \rho_1'(\lambda) \qquad (17)$$

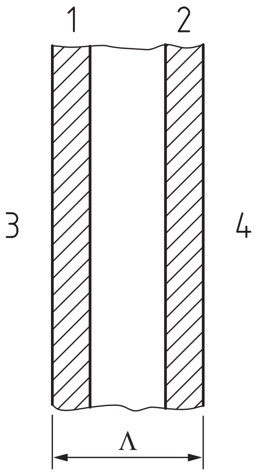
$\alpha_2(\lambda)$ is the spectral direct absorptance of the second pane, measured in the direction of the incident radiation, given by the formula:

$$\alpha_2(\lambda) = 1 - \tau_2(\lambda) - \rho_2(\lambda) \qquad (18)$$

S_λ and $\Delta\lambda$ are as defined in 5.4.3;

$\tau_1(\lambda)$, $\rho_2(\lambda)$ and $\rho_1'(\lambda)$ are as defined in 5.2.

The thermal conductance Λ is determined by the calculation method in accordance with EN 673 whenever possible or by measuring methods in accordance with EN 674 or EN 675.



Key

1 pane 1
2 pane 2
3 outside
4 inside

Figure 4 — Illustration of the meaning of thermal conductance Λ

5.4.6.4 Triple glazing

The secondary internal heat transfer factor of triple glazing, q_i, is calculated using the following formula:

$$q_\mathrm{i} = \frac{\left[\frac{\alpha_\mathrm{e3}}{\Lambda_{23}} + \frac{\alpha_\mathrm{e3}+\alpha_\mathrm{e2}}{\Lambda_{12}} + \frac{\alpha_\mathrm{e3}+\alpha_\mathrm{e2}+\alpha_\mathrm{e1}}{h_\mathrm{e}}\right]}{\left[\frac{1}{h_\mathrm{i}} + \frac{1}{h_\mathrm{e}} + \frac{1}{\Lambda_{12}} + \frac{1}{\Lambda_{23}}\right]} \tag{19}$$

where

α_e1 is the solar direct absorptance of the outer pane within the triple glazing;

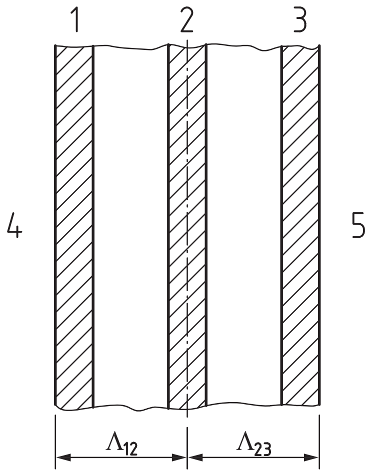
α_e2 is the solar direct absorptance of the second pane within the triple glazing;

α_e3 is the solar direct absorptance of the third pane within the triple glazing;

h_e and h_i are the heat transfer coefficients towards the outside and inside respectively in accordance with 5.4.6.1;

Λ_{12} is the thermal conductance between the outer surface of the first pane and the centre of the second pane (see Figure 5);

Λ_{23} is the thermal conductance between the centre of the second pane and the innermost surface of the third pane (see Figure 5).



Key

1 pane 1
2 pane 2
3 pane 3
4 outside
5 inside

Figure 5 — Illustration of the meaning of the thermal conductances Λ_{12} and Λ_{23}

α_{e1}, α_{e2} and α_{e3} are calculated as follows:

$$\alpha_{\mathrm{e1}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \left\{ \alpha_1(\lambda) + \frac{\tau_1(\lambda)\alpha_1'(\lambda)\rho_2(\lambda)\left[1-\rho_2'(\lambda)\rho_3(\lambda)\right]+\tau_1(\lambda)\tau_2^2(\lambda)\alpha_1'(\lambda)\rho_3(\lambda)}{\left[1-\rho_1'(\lambda)\rho_2(\lambda)\right]\times\left[1-\rho_2'(\lambda)\rho_3(\lambda)\right]-\tau_2^2(\lambda)\rho_1'(\lambda)\rho_3(\lambda)} \right\} \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \Delta\lambda} \tag{20}$$

$$\alpha_{\mathrm{e2}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \left\{ \frac{\tau_1(\lambda)\alpha_2(\lambda)\left[1-\rho_2'(\lambda)\rho_3(\lambda)\right]+\tau_1(\lambda)\tau_2(\lambda)\alpha_2'(\lambda)\rho_3(\lambda)}{\left[1-\rho_1'(\lambda)\rho_2(\lambda)\right]\times\left[1-\rho_2'(\lambda)\rho_3(\lambda)\right]-\tau_2^2(\lambda)\rho_1'(\lambda)\rho_3(\lambda)} \right\} \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \Delta\lambda} \tag{21}$$

$$\alpha_{\mathrm{e3}} = \frac{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \left\{ \frac{\tau_1(\lambda)\tau_2(\lambda)\alpha_3(\lambda)}{\left[1-\rho_1'(\lambda)\rho_2(\lambda)\right]\times\left[1-\rho_2'(\lambda)\rho_3(\lambda)\right]-\tau_2^2(\lambda)\rho_1'(\lambda)\rho_3(\lambda)} \right\} \Delta\lambda}{\sum_{\lambda=300\ \mathrm{nm}}^{2500\ \mathrm{nm}} \mathsf{S}_\lambda \Delta\lambda} \tag{22}$$

where

$\alpha_1(\lambda)$, $\alpha_1'(\lambda)$ and $\alpha_{2(\lambda)}$ are as defined in 5.4.6.3;

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

$$\alpha_2'(\lambda) = 1 - \tau_2(\lambda) - \rho_2'(\lambda) \tag{23}$$

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

$$\alpha_3(\lambda) = 1 - \tau_3(\lambda) - \rho_3(\lambda) \tag{24}$$

S_λ and $\Delta\lambda$ are as defined in 5.4.3.

The thermal conductances Λ_{12} and Λ_{23} are determined in accordance with 5.4.6.3.

5.5 UV-transmittance

In the UV range, the global radiation of the sun contains components in the UV-B range 280 nm to 315 nm and the UV-A range 315 nm to 380 nm. A standard relative spectral distribution for the UV part of the global solar radiation, U_λ, is given (see Bibliography, [7]). Table 3 gives the values of $U_\lambda \Delta\lambda$ for wavelength intervals of 5 nm in the UV range. The table has been drawn up with relative values in such a way that $\sum U_\lambda \Delta\lambda = 1$ for the total UV range.

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

$$\tau_{uv} = \frac{\sum_{\lambda=280\ \mathrm{nm}}^{380\ \mathrm{nm}} U_\lambda \tau(\lambda) \Delta\lambda}{\sum_{\lambda=280\ \mathrm{nm}}^{380\ \mathrm{nm}} U_\lambda \Delta\lambda} \tag{25}$$

where

$\tau(\lambda)$ is the spectral direct transmittance of the glazing (see 5.2);

U_λ is the relative distribution of the UV part of global solar radiation;

$\Delta\lambda$ is the wavelength interval.

NOTE If statements are made about the UV transmission of glazing, in most cases it is sufficient to give τ_{uv}, the transmittance for the total UV radiation contained in global solar radiation. Only in special cases would there be any interest in the transmittances for the sub-ranges UV-A and UV-B.

5.6 Colour rendering

The colour rendering properties of glazing in transmission are expressed by the general colour rendering index R_a. This index enables to express synthetically a quantitative evaluation of the differences in colour between eight test colours lighted directly by the reference illuminant D65 and by the same illuminant transmitted through the glazing (see Bibliography, [8]).

NOTE Bibliography, [8] suggests to determine the colour rendering index with the help of a diskette. The user should be aware of the fact that the program contained in the diskette automatically compares the light filtered by a given glazing with the illuminant having the nearest colour temperature, rather than with D65.

The test colours are defined by their spectral reflectance $\beta_i(\lambda)$ (*i* from 1 to 8), reported in Table 4 (see Bibliography, [8]). The relative spectral energy distribution of illuminant D65 is reported in Table 5 (see Bibliography, [5]).

The procedure to determine the general colour rendering index is the following.

Calculate the tristimulus values X_t, Y_t, Z_t of the light transmitted by the glazing:

$$\mathrm{X_t} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \bar{x}(\lambda)\, \Delta\lambda \tag{26}$$

$$\mathrm{Y_t} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \bar{y}(\lambda)\, \Delta\lambda \tag{27}$$

$$\mathrm{Z_t} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \bar{z}(\lambda)\, \Delta\lambda \tag{28}$$

where

$\frac{d\phi_e}{d\lambda} \Delta\lambda$ is the relative spectral energy distribution of illuminant D65 reported in Table 5 (see Bibliography, [5]));

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

$\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ are the spectral tristimulus values for the CIE 1931 colorimetric standard observer reported in Table 6 (see Bibliography, [5])).

Calculate the tristimulus values of the light transmitted by the glazing and reflected by each of the eight test colours:

$$\mathrm{X_{t,i}} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \beta_\mathrm{i}(\lambda)\, \bar{x}(\lambda)\, \Delta\lambda \tag{29}$$

$$\mathrm{Y_{t,i}} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \beta_\mathrm{i}(\lambda)\, \bar{y}(\lambda)\, \Delta\lambda \tag{30}$$

$$\mathrm{Z_{t,i}} = \sum_{\lambda=380\ \mathrm{nm}}^{780\ \mathrm{nm}} \frac{d\phi_e}{d\lambda} \tau(\lambda)\, \beta_\mathrm{i}(\lambda)\, \bar{z}(\lambda)\, \Delta\lambda \tag{31}$$

where

$\beta_\mathrm{i}(\lambda)$ is the spectral reflectance of each test colour *i* (*i* from 1 to 8).

Calculate the trichromatic coordinates in the CIE 1960 uniform chromaticity diagram. The following formulae shall be used:

- for transmitted light:

$$\mathrm{u_t} = \frac{4\mathrm{X_t}}{\mathrm{X_t} + 15\mathrm{Y_t} + 3\mathrm{Z_t}} \tag{32}$$

$$v_t = \frac{6Y_t}{X_t + 15Y_t + 3Z_t} \tag{33}$$

— for light transmitted then reflected by the test colour *i*:

$$u_{t,i} = \frac{4X_{t,i}}{X_{t,i} + 15Y_{t,i} + 3Z_{t,i}} \tag{34}$$

$$v_{t,i} = \frac{6Y_{t,i}}{X_{t,i} + 15Y_{t,i} + 3Z_{t,i}} \tag{35}$$

Calculate the trichromatic coordinates corrected in terms of distortion by chromatic adaptation, for the eight test colours illuminated by the transmitted light according to:

$$u'_{t,i} = \frac{10{,}872 + 0{,}8802\frac{c_{t,i}}{c_t} - 8{,}2544\frac{d_{t,i}}{d_t}}{16{,}518 + 3{,}2267\frac{c_{t,i}}{c_t} - 2{,}0636\frac{d_{t,i}}{d_t}} \tag{36}$$

$$v'_{t,i} = \frac{5{,}520}{16{,}518 + 3{,}2267\frac{c_{t,i}}{c_t} - 2{,}0636\frac{d_{t,i}}{d_t}} \tag{37}$$

with c_t; d_t for the transmitted light, $c_{t,i}$; $d_{t,i}$ for each test colour i, expressed by the formulae:

— for transmitted light:

$$c_t = \frac{1}{v_t}(4 - u_t - 10v_t) \tag{38}$$

$$d_t = \frac{1}{v_t}(1{,}708v_t + 0{,}404 - 1{,}48u_t) \tag{39}$$

— for light transmitted, then reflected by the test colour i:

$$c_{t,i} = \frac{1}{v_{t,i}}(4 - u_{t,i} - 10v_{t,i}) \tag{40}$$

$$d_{t,i} = \frac{1}{v_{t,i}}(1{,}708v_{t,i} + 0{,}404 - 1.48u_{t,i}) \tag{41}$$

Conversion into the CIE 1964 uniform colour space system: for each of the test colours the conversion is worked out using the formulae:

$$W^*_{t,i} = 25\left(\frac{100Y_{t,i}}{Y_t}\right)^{\frac{1}{3}} - 17 \qquad (42)$$

$$U^*_{t,i} = 13W^*_{t,i}\left(u'_{t,i} - 0,1978\right) \qquad (43)$$

$$V^*_{t,i} = 13W^*_{t,i}\left(v'_{t,i} - 0,3122\right) \qquad (44)$$

Determination of the total distortion of the colour *i*. For each test colour i:

$$\Delta E_i = \sqrt{\left(U^*_{t,i} - U^*_{r,i}\right)^2 + \left(V^*_{t,i} - V^*_{r,i}\right)^2 + \left(W^*_{t,i} - W^*_{r,i}\right)^2} \qquad (45)$$

The values of $U^*_{r,i}$; $V^*_{r,i}$; $W^*_{r,i}$ calculated for the test colours, lighted by the standard illuminant D65 without the glazing being interposed, are given in Table 7 (see [8]).

Calculate the specific colour rendering index for each test colour i:

$$R_i = 100 - 4,6\Delta E_i \qquad (46)$$

Calculate the general colour rendering index:

$$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i \qquad (47)$$

The general colour rendering index R_a may attain 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 $R_a > 90$ characterize a very good and values $R_a > 80$ a good colour rendering.

An example of calculation of R_a is given in Annex E.

5.7 Shading coefficient

The shading coefficient, SC, is calculated in accordance with the following formula:

$$SC = \frac{g}{0.87} \qquad (48)$$

NOTE 1 In some countries, SC may be specifically referred to as total shading coefficient.

NOTE 2 The value of 0,87 traditionally corresponds to the total energy transmittance of a clear float glass of nominal thickness of 3 mm to 4mm.

6 Expression of results

The general colour rendering index R_a shall be quoted to two significant figures. All the other characteristics shall be quoted to two decimal places. Intermediate values shall not be rounded.

7 Test report

The test report shall state the following:

a) the number and thickness of panes in the glazing;

b) the type and position of panes (for the case of multiple glazing) designated as outer pane, second inner pane, third inner pane, etc.;

c) the position of the coating (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;

d) the results for the required characteristics;

e) the type of instrument used (specifying, if used, the reflectance accessory or integrating sphere and the reference material for reflectance).

Table 1 — Normalized relative spectral distribution D_λ of illuminant D_{65} multiplied by the spectral luminous efficiency $V(\lambda)$ and by the wavelength interval $\Delta\lambda$

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

Table 2 — Normalized relative spectral distribution of global solar radiation S_λ multiplied by the wavelength interval $\Delta\lambda$

λ nm	$S_\lambda \Delta_\lambda$ [a]	λ nm	$S_\lambda \Delta_\lambda$ [a]
300	0,0005	1000	0,0329
320	0,0069	1050	0,0306
340	0,0122	1100	0,0185
360	0,0145	1150	0,0136
380	0,0177	1200	0,0210
400	0,0235	1250	0,0211
420	0,0268	1300	0,0166
440	0,0294	1350	0,0042
460	0,0343	1400	0,0010
480	0,0339	1450	0,0044
500	0,0326	1500	0,0095
520	0,0318	1550	0,0123
540	0,0321	1600	0,0110
560	0,0312	1650	0,0106
580	0,0294	1700	0,0093
600	0,0289	1750	0,0068
620	0,0289	1800	0,0024
640	0,0280	1850	0,0005
660	0,0273	1900	0,0002
680	0,0246	1950	0,0012
700	0,0237	2000	0,0030
720	0,0220	2050	0,0037
740	0,0230	2100	0,0057
760	0,0199	2200	0,0066
780	0,0211	2300	0,0060
800	0,0330	2400	0,0041
850	0,0453	2500	0,0006
900	0,0381		
950	0,0220		

[a] The relative spectral distribution of global solar radiation (direct and diffuse) is calculated from the values given in Bibliography, [6] for air mass= 1; water content = 1,42 cm precipitable water; ozone content = 0,34 cm at standard temperature and pressure; albedo of earth surface = 0,2; spectral optical depth of aerosol extinction (at λ = 500 nm)= 0,1.

Table 3 — Normalized relative spectral distribution of the UV part of the global solar radiation multiplied by the wavelength interval $\Delta\lambda$

λ nm	$U_\lambda \Delta\lambda$
300	0,000 63
305	0,005 54
310	0,014 71
315	0,027 50
320	0,039 75
325	0,051 25
330	0,067 57
335	0,068 22
340	0,071 83
345	0,072 42
350	0,076 81
355	0,078 86
360	0,081 42
365	0,090 22
370	0,099 11
375	0,102 23
380	0,051 93

Table 4 — Spectral reflectance of the eight test colours (1 to 8) to be used to calculate the general colour rendering index

λ	Test colour number							
nm	1	2	3	4	5	6	7	8
380	0,219	0,070	0,065	0,074	0,295	0,151	0,378	0,104
390	0,252	0,089	0,070	0,093	0,310	0,265	0,524	0,170
400	0,256	0,111	0,073	0,116	0,313	0,410	0,551	0,319
410	0,252	0,118	0,074	0,124	0,319	0,492	0,559	0,462
420	0,244	0,121	0,074	0,128	0,326	0,517	0,561	0,490
430	0,237	0,122	0,073	0,135	0,334	0,531	0,556	0,482
440	0,230	0,123	0,073	0,144	0,346	0,544	0,544	0,462
450	0,225	0,127	0,074	0,161	0,360	0,556	0,522	0,439
460	0,220	0,131	0,077	0,186	0,381	0,554	0,488	0,413
470	0,216	0,138	0,085	0,229	0,403	0,541	0,448	0,382
480	0,214	0,150	0,109	0,281	0,415	0,519	0,408	0,352
490	0,216	0,174	0,148	0,332	0,419	0,488	0,363	0,325
500	0,223	0,207	0,198	0,370	0,413	0,450	0,324	0,299
510	0,226	0,242	0,241	0,390	0,403	0,414	0,301	0,283
520	0,225	0,260	0,278	0,395	0,389	0,377	0,283	0,270
530	0,227	0,267	0,339	0,385	0,372	0,341	0,265	0,256
540	0,236	0,272	0,392	0,367	0,353	0,309	0,257	0,250
550	0,253	0,282	0,400	0,341	0,331	0,279	0,259	0,254
560	0,272	0,299	0,380	0,312	0,308	0,253	0,260	0,264
570	0,298	0,322	0,349	0,280	0,284	0,234	0,256	0,272
580	0,341	0,335	0,315	0,247	0,260	0,225	0,254	0,278
590	0,390	0,341	0,285	0,214	0,232	0,221	0,270	0,295
600	0,424	0,342	0,264	0,185	0,210	0,220	0,302	0,348
610	0,442	0,342	0,252	0,169	0,194	0,220	0,344	0,434

Table 4 *(continued)*

λ nm	Test colour number							
	1	2	3	4	5	6	7	8
620	0,450	0,341	0,241	0,160	0,185	0,223	0,377	0,528
630	0,451	0,339	0,229	0,154	0,180	0,233	0,400	0,604
640	0,451	0,338	0,220	0,151	0,176	0,244	0,420	0,648
650	0,450	0,336	0,216	0,148	0,175	0,258	0,438	0,676
660	0,451	0,334	0,219	0,148	0,175	0,268	0,452	0,693
670	0,453	0,332	0,230	0,151	0,180	0,278	0,462	0,705
680	0,455	0,331	0,251	0,158	0,186	0,283	0,468	0,712
690	0,458	0,329	0,288	0,165	0,192	0,291	0,473	0,717
700	0,462	0,328	0,340	0,170	0,199	0,302	0,483	0,721
710	0,464	0,326	0,390	0,170	0,199	0,325	0,496	0,719
720	0,466	0,324	0,431	0,166	0,196	0,351	0,511	0,725
730	0,466	0,324	0,460	0,164	0,195	0,376	0,525	0,729
740	0,467	0,322	0,481	0,168	0,197	0,401	0,539	0,730
750	0,467	0,320	0,493	0,177	0,203	0,425	0,553	0,730
760	0,467	0,316	0,500	0,185	0,208	0,447	0,565	0,730
770	0,467	0,315	0,505	0,192	0,215	0,469	0,575	0,730
780	0,467	0,314	0,516	0,197	0,219	0,485	0,581	0,730

Table 5 — Relative spectral power distribution of illuminant D65 for wavelengths between 380 nm and 780 nm normalized to the value of 100 at 560 nm

λ	spectral flux	λ	spectral flux
nm	$\frac{d\phi_E}{d\lambda}\Delta\lambda$	nm	$\frac{d\phi_E}{d\lambda}\Delta\lambda$
380	50,0	580	95,8
390	54,6	590	88,7
400	82,8	600	90,0
410	91,5	610	89,6
420	93,4	620	87,7
430	86,7	630	83,3
440	104,9	640	83,7
450	117,0	650	80,0
460	117,8	660	80,2
470	114,9	670	82,3
480	115,9	680	78,3
490	108,8	690	69,7
500	109,4	700	71,6
510	107,8	710	74,3
520	104,8	720	61,6
530	107,7	730	69,9
540	104,4	740	75,1
550	104,0	750	63,6
560	100,0	760	46,4
570	96,3	770	66,8
		780	63,4

Table 6 — CIE 1931 standard colorimetric (2 degree) observer. Abridged set of spectral tristimulus values $\bar{x}(\lambda)$, $\bar{y}(\lambda)$, $\bar{z}(\lambda)$ for λ = 380 nm to 780 nm at 10 nm intervals

λ, nm	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$
380	0,001368	0,000039	0,006450
390	0,004243	0,000120	0,020050
400	0,014310	0,000396	0,067850
410	0,043510	0,001210	0,207400
420	0,134380	0,004000	0,645600
430	0,283900	0,011600	1,385600
440	0,348280	0,023000	1,747060
450	0,336200	0,038000	1,772110
460	0,290800	0,060000	1,669200
470	0,195360	0,090980	1,287640
480	0,095640	0,139020	0,812950
490	0,032010	0,208020	0,465180
500	0,004900	0,323000	0,272000
510	0,009300	0,503000	0,158200
520	0,063270	0,710000	0,078250
530	0,165500	0,862000	0,042160
540	0,290400	0,954000	0,020300
550	0,433450	0,994950	0,008750
560	0,594500	0,995000	0,003900
570	0,762100	0,952000	0,002100
580	0,916300	0,870000	0,001650
590	1,026300	0,757000	0,001100
600	1,062200	0,631000	0,000800
610	1,002600	0,503000	0,000340

Table 6 *(continued)*

λ, nm	$\bar{x}(\lambda)$	$\bar{y}(\lambda)$	$\bar{z}(\lambda)$
620	0,854450	0,381000	0,000190
630	0,642400	0,265000	0,000050
640	0,447900	0,175000	0,000020
650	0,283500	0,107000	0,000000
660	0,164900	0,061000	0,000000
670	0,087400	0,032000	0,000000
680	0,046770	0,017000	0,000000
690	0,022700	0,008210	0,000000
700	0,011359	0,004102	0,000000
710	0,005790	0,002091	0,000000
720	0,002899	0,001047	0,000000
730	0,001440	0,000520	0,000000
740	0,000690	0,000249	0,000000
750	0,000332	0,000120	0,000000
760	0,000166	0,000060	0,000000
770	0,000083	0,000030	0,000000
780	0,000042	0,000015	0,000000

Table 7 — Values of $U^*_{r,i}$, $V^*_{r,i}$, $W^*_{r,i}$ for the test colours lighted by the standard illuminant D65

Test colour number	$U^*_{r,i}$	$V^*_{r,i}$	$W^*_{r,i}$
1	31,92	8,41	60,48
2	15,22	23,76	59,73
3	-8,34	36,29	61,08
4	-33,29	18,64	60,25
5	-26,82	-6,55	61,41
6	-18,80	-28,80	60,52
7	9,77	-26,50	60,14
8	28,78	-16,24	61,83

Annex A
(normative)

Procedures for calculation of the spectral characteristics of glass plates with a different thickness and/or colour

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

All transmittance and reflectance values in the following shall be as fractions (i.e. 0 to 1) rather than percentages (i.e. o to 100).

Knowing:

$\tau_x(\lambda)$ is the spectral transmittance of a glass plate with thickness *x;*

$n(\lambda)$ is the refractive index of the glass (for soda lime glass see Bibliography [9]).

the spectral transmittance for thickness *y* is calculated using the formula:

$$\tau_y(\lambda) = \frac{[1-\rho_s(\lambda)]^2 \tau_{i,y}(\lambda)}{1-\rho_s^2(\lambda)\tau_{i,y}^2(\lambda)} \tag{A.1}$$

where

$\rho_s(\lambda)$ designates reflectance at the air-glass interface in accordance with the following formula:

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

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

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

where

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

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

In a similar way the spectral reflectance is calculated for a thickness *y* in accordance with the following formula:

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

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:

$\mathrm{x} = 3,00$

$\tau_\mathrm{x} = 0,83$

$n = 1,525$

$\mathrm{y} = 5,00$

Formula (A2) gives $\rho_\mathrm{s} = 0,0432$

Formula (A4) gives $\tau_\mathrm{i,x} = 0,9053$

Formula (A3) gives $\tau_\mathrm{i,y} = 0,8472$

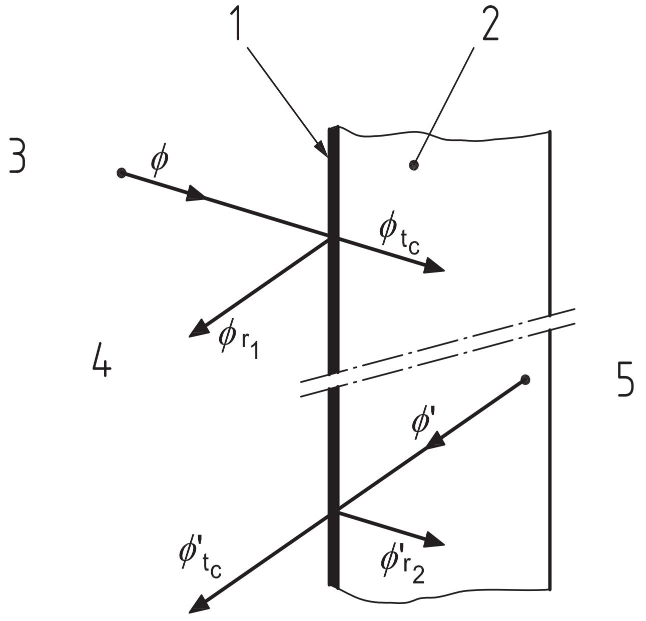
Formula (A1) gives $\tau_\mathrm{y} = 0,7766$ rounded to $0,78$

Formula (A5) gives $\rho_\mathrm{y} = 0,0717$ 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 has been deposited

A.2.1 Intrinsic characteristics of the system air-coating-glass

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



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

1) $r_1(\lambda)$: spectral reflectance of the coating for light incident from the air towards the coating;

2) $r_2(\lambda)$: spectral reflectance of the coating for light incident from the glass towards the coating;

3) $t_c(\lambda)$: spectral transmittance of the system: air - coating - substrate.

The values of such characteristics are calculated from the measured spectral characteristics

$[\rho_s(\lambda), \tau_i(\lambda)]$ of a sample of previously characterized glass on which the coating has been deposited. The following characteristics shall be measured:

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

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

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

The following formulae are applied:

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

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

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

where

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

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

A.2.2 Characteristics of the same coating on a different glass

From such intrinsic characteristics of the system air-coating-glass one can calculate 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 (see Bibliography [9]).

The following formulae are valid:

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

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

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

where

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

$\tau_i(\lambda)$ 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. n = 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 is obtained:

$\tau_i = 0,9749$for a clear glass of 6,00 mm thickness.

Equation (A.9) gives $\mathrm{D} = 0,9258$

Equation (A.6) gives $\mathrm{r}_1 = 0,3384$

Equation (A.7) gives $\mathrm{r}_2 = 0,2725$

Equation (A.8) gives $\mathrm{t}_c = 0,3997$

The application of the Equations (A.10) to (A.13) requires the 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):

$$\tau_i = (0,9053)^{\frac{4}{3}} = 0,8758$$

Equation (A.13) gives $\mathrm{D}' = 0,9910$

Equation (A.10) gives $\rho_1(\lambda) = 0,3437$ rounded to $0,34$

Equation (A.11) gives $\rho_2(\lambda) = 0,2363$ rounded to $0,24$

Equation (A.12) gives $\tau = 0,3379$ rounded to $0,34$

Annex B
(normative)

Procedure for calculation of the spectral characteristics of laminated glass

B.1 Introduction

In the following Annex, calculations of transmission and reflection from both sides are given for the case of having one medium between two interfaces and the case of having two media between three interfaces, i.e. as in the case for laminated glass with a coating between the interlayer and one of the glass panes. Calculations in the forward sense, i.e. total transmission and reflections determined from the interface transmissions and reflections and internal transmissions of the media, are provided as well as calculations in the reverse sense, i.e. interface transmissions and reflections and internal transmissions of the media determined from total transmission and reflections or measured total transmission and reflections of the systems.

It should be noted that all parameters are wavelength-dependent. However, the following formulae are valid for any wavelength. Another point is the fact that there are only three measurable parameters of any system (transmission and reflections from both sides), limiting the number of interface and media parameters that can be determined from any one measurement set to three.

This Annex provides the exact formulae for the calculations of spectral parameters of single glazing, either coated or not, and of laminated glazing where any or all of the interfaces are coated. In addition, examples are presented to demonstrate these calculations. Numerical calculation results are presented to six significant figures, not to signify that the results have this level of precision, but to allow verification of calculations.

B.2 Terminology

In this Annex, the system shall be considered as a certain number of interfaces separated by media and the positive direction as light impinging from the left and propagating to the right. Both media and interfaces are numbered from left to right.

The interfaces are defined as having a transmission and reflections from both sides. These parameters are denoted as follow:

t_i : transmission of the i^{th} interface (equivalent for both directions)

r_i : reflection of the i^{th} interface of light impinging from the positive direction

r_i' : reflection of the i^{th} interface of light impinging from the negative direction

The parameters of each medium are denoted as:

τ_i : internal transmission of the i^{th} medium (equivalent for both directions)

d_i : thickness of the i^{th} medium

Total transmission and reflections (including multiple internal reflections) calculated from the media and interface parameters (or measured) are denoted as:

τ_T = total transmission of the system

ρ_T = total reflection of the system of light impinging from the positive direction

$\rho_T^{'}$ = total reflection of the system of light impinging from the negative direction

B.3 Basic equations

B.3.1 General

A certain number of basic relations are used throughout the Annex.

B.3.2 Internal transmission of a medium with the same extinction coefficient as another but with a different thickness

The internal transmission of a media is given by Equation (B.1).

$$\tau = e^{-\frac{4\pi k(\lambda)d}{\lambda}} \tag{B.1}$$

where

$k\,(\lambda)$ is the extinction coefficient of the medium at wavelength λ with a thickness of d

Therefore, if two media have the same extinction coefficient but different thicknesses then their internal transmissions are related in Equation (B.2).

$$\tau_1 = \tau_2^{d_1/d_2} \tag{B.2}$$

where

τ_1 and d_1 are the internal transmission and thickness of the first medium

τ_2 and d_2 are the internal transmission and thickness of the second medium

Equation (B.2) is useful in the case where the internal transmission of one glass pane is desired using measurements on another pane with the same extinction coefficient, but a different thickness. Similarly, B.2 can also be applied to interlayers with different thicknesses.

B.3.3 Total internal transmission of two adjoining media with equivalent refractive indices

When two adjoining media have equivalent refractive indices the interface separating them has zero reflection and 100 % transmission. In this case, the effective internal transmission of the two (or more) media is given in the Equation (B.3).

$$\tau = \tau_1 \tau_2 \tag{B.3}$$

where

τ is the effective internal transmission of the combination of the two media

τ_1 and τ_2 are the internal transmissions of the two media

This relation is useful in the case of laminated glazing where the interlayer has the same refractive index as the glass pane(s) but a different extinction coefficient.

B.3.4 Transmission and reflection of a non-absorbing interface

In the case of a non-absorbing interface, it is sufficient to describe the interface by either its transmission or reflection. This is because of the relationships given in Equation (B.4).

$$t_i + r_i = 1 \qquad \text{and} \qquad r_i' = r_i \tag{B.4}$$

where

T_i, R_i and R_i' are the transmission and reflections from both sides of the i^{th} interface

B.4 Systems with two interfaces

B.4.1 Calculations of the total transmission and reflections from the interface and media parameters

Figure B.1 shows a system of two interfaces separated by one medium.

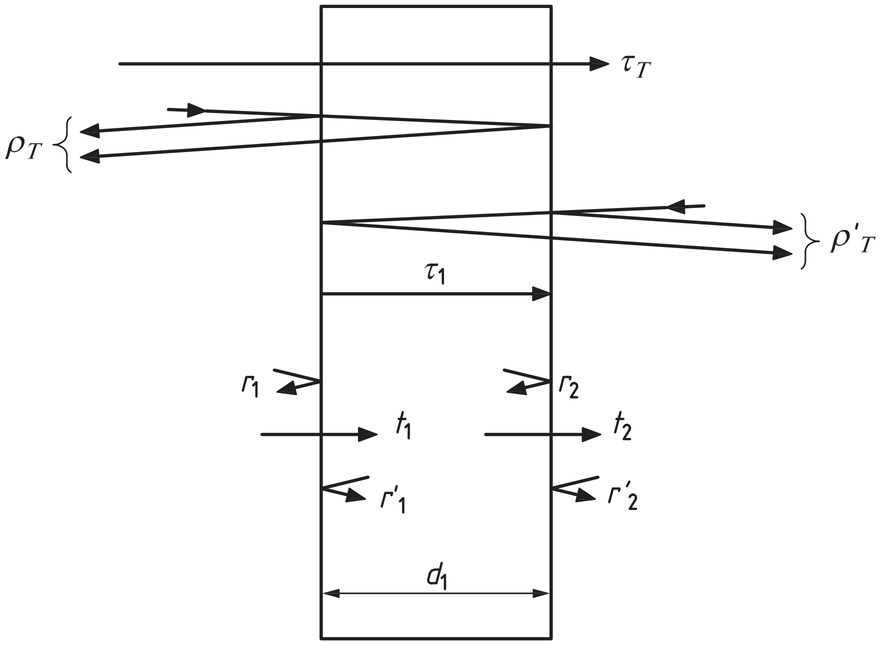


Figure B.1 — System of two interfaces separated by one medium

In Figure B.1, two interfaces separated by one medium can be defined by the following characteristics:

τ_T = total transmission of the system including internal multiple reflections

ρ_T = total reflection of light incident from the left of the system including internal multiple reflections

$\rho_T^{'}$ = total reflection of light incident from the right of the system including internal multiple reflections

t_1 = transmission of interface 1

r_1 = reflection of interface 1 from light incident from the left

$r_1^{'}$ = reflection of interface 1 from light incident from the right

t_2 = transmission of interface 2

r_2 = reflection of interface 2 from light incident from the left

$r_2^{'}$ = reflection of interface 2 from light incident from the right

τ_1 = internal transmission of medium 1

d_1 = thickness of medium 1

The total transmission and reflections shall be calculated from the interface and media parameters using Equations (B.5), (B.6) and (B.7).

$$\tau_T = \frac{t_1 \tau_1 t_2}{1 - r_1^{'} \tau_1^2 r_2} \qquad \text{(B.5)}$$

$$\rho_T = r_1 + \frac{t_1^2 \tau_1^2 r_2}{1 - r_1^{'} \tau_1^2 r_2} \qquad \text{(B.6)}$$

$$\rho_T^{'} = r_2^{'} + \frac{r_1^{'} \tau_1^2 t_2^2}{1 - r_1^{'} \tau_1^2 r_2} \qquad \text{(B.7)}$$

The procedure can be illustrated in the numerical example provided below.

Let

t_1 = 0,600000, r_1 = 0,200000, and $r_1^{'}$ =0,150000
τ_1 = 0,940000
t_2 = 0,850000, r_2 = 0,070000, and $r_2^{'}$ =0,090000

The total transmission and reflections of the system are:

τ_T = 0,483889
ρ_T = 0,222475
$\rho_T^{'}$ = 0,186657

B.4.2 Calculations of the interface and media parameters from the total transmission and reflections

B.4.2.1 Determination of the internal transmission and interface reflections of an uncoated glass pane

In theory, with the case of an uncoated glass pane, Equations (B.5), (B.6) and (B.7) can be used to determine the internal transmission and interface reflections. As the interfaces are uncoated they are also non-absorbing, i.e. Equation (B.4) can be applied. Note the system is symmetric and $\rho_T^{'} = \rho_T$.

Equation (B.8) shall be used to determine interface reflections of the glass pane.

$$r_1 = r_2 = \frac{-b - \sqrt{b^2 - 4ac}}{2a} \qquad a = 2 - \rho_T, \qquad b = \rho_T^2 - \tau_T^2 - 2\rho_T - 1 \qquad c = \rho_T \tag{B.8}$$

Note that the negative root of the discriminant is used.

where

τ_1 — is the internal transmission of the glass pane

r_1 and r_2 are the reflections of the interfaces

τ_T and ρ_T are the measured total transmission and reflection of the glass pane

The internal transmission shall be determined using Equation (B.9).

$$\tau_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad a = \tau_T r_1^2, \qquad b = (1.0 - r_1)^2 \qquad c = -\tau_T \tag{B.9}$$

In this case, note that the positive root of the discriminant is used.

Alternately, the internal transmission can be determined using Equation (B.10).

$$\tau_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad a = 1, \qquad b = \frac{1 + \rho_T^2 - \tau_T^2 - 2\rho_T}{\tau_T} \qquad c = -1 \tag{B.10}$$

Note that the positive root of the discriminant is used.

The reflection of the interfaces can then be determined by Equation (B.11).

$$r_1 = r_2 = \frac{\rho_T}{1 + \tau_1 \tau_T} \tag{B.11}$$

The procedure can be illustrated in the numerical example provided below.

If the measured total transmission and reflection values are:

τ_T = 0,895300

$\rho_{T'}$ = 0,074738

Then the internal transmission is $\tau_1 =$0,970000 and the interface reflections are: $r_1 = r_2$ = 0,040000.

In practice, r_1 is usually determined indirectly by determining the complex refractive index of the glass and deducing the reflection from this value. For normal incidence, the reflection shall be determined from Equation (B.12).

$$r_1 = \frac{(n-1)^2 + k^2}{(n+1)^2 + k^2} \tag{B.12}$$

where $\hat{n} = n - ik$, n being the refractive index and k being the extinction coefficient of the glass.

Over the solar range $k << n$ for soda lime glass and Equation (B.12) essentially becomes Equation (B.13).

$$r_1 = \left(\frac{n-1}{n+1}\right)^2 \tag{B.13}$$

The internal transmission is then determined using Equation (B.9). This technique is preferred to using equation (B.8) unless very accurate reflection measurements are available.

This procedure is illustrated by the following numerical example, in which the refractive index has been determined to be 1,52 and the total measured transmission is 0,89.

Equations (B.13) and (B.9) give

$$r_1 = 0{,}042580 \text{ and}$$
$$\tau_1 = 0{,}969270$$

If the internal transmission of a different thickness of the same glass is required, Equation (B.2) can be used.

B.4.2.2 Determination of the interface parameters of a glass pane coated on only one interface and where the parameters of the second interface have previously been determined

If the transmission and reflections of a coated interface are unknown, they can be determined provided that the internal transmission of the glass pane has previously been determined by procedure B.4.2.1 above, and the interface parameters $(t_2, r_2, \text{and } r_2^{'})$ of the opposite interface have been previously determined either by procedure B.4.2.1 above or this procedure. If the absorbing layer is on interface 1, the transmission and reflections are given by Equations (B.14), (B.15) and (B.16).

$$t_1 = \frac{\tau_T t_2}{\tau_1(t_2^2 - r_2 r_2^{'} + \rho_T^{'} r_2)} \tag{B.14}$$

$$r_1 = \frac{\rho_T(t_2^2 - r_2 r_2^{'}) - r_2(\tau_T^2 - \rho_T \rho_{T'})}{t_2^2 - r_2 r_2^{'} + \rho_T^{'} r_2} \tag{B.15}$$

$$r_1' = \frac{\rho_T' - r_2'}{\tau_1^2 (t_2^2 - r_2 r_2' + \rho_T' r_2)} \tag{B.16}$$

The procedure is illustrated in the following numerical example (also see above).

If the measured total transmission and reflection values are:

$$\begin{aligned} \tau_T &= 0{,}483889 \\ \rho_T &= 0{,}222475 \\ \rho_T' &= 0{,}186657 \end{aligned}$$

and the previously determined values of the internal transmission of the medium and the transmission and reflections values of the second interface are:

$$\tau_1 = 0{,}940000$$
$$t_2 = 0{,}850000,\ r_2 = 0{,}070000, \text{ and } r_2' = 0{,}090000$$

Then Equations (B.14), (B.15), and (B.16) yield:

$$t_1 = 0{,}600000,\ r_1 = 0{,}200000, \text{ and } r_1' = 0{,}150000$$

While Equations (B.14), (B.15), and (B.16) allow these calculations for the general case, the most common method is to determine the parameters of the coated side with the opposite side uncoated, i.e. we can use Equations (B.13) and (B.4) to determine the parameters of the uncoated side through knowledge of the refractive index of the glass using Equations (B.17), (B.18) and (B.19).

$$t_1 = \frac{\tau_T (1 - r_2)}{\tau_1 (1 - 2r_2 + \rho_T r_2)} \tag{B.17}$$

$$r_1 = \frac{\rho_T (1 - 2r_2) - r_2 \left(\tau_T^2 - \rho_T \rho_T'\right)}{1 - 2r_2 + \rho_T r_2} \tag{B.18}$$

$$r_1' = \frac{\rho_T' - r_2}{\tau_1^2 (1 - 2r_2 + \rho_T r_2)} \tag{B.19}$$

The procedure is illustrated by the following numerical example, in which the refractive index has been determined to be 1.52 - as in the above example - giving $r_2 = 0{,}042580$.

If

$$\begin{aligned} \tau_T &= 0{,}640000 \\ \rho_T &= 0{,}220000 \\ \rho_T' &= 0{,}170000 \end{aligned}$$

Equations (B.17), (B.18) and (B.19) give the following:

$$\begin{aligned} t_1 &= 0{,}692219 \\ r_1 &= 0{,}201085 \\ r_1' &= 0{,}149943 \end{aligned}$$

B.4.2.3 Determination of the internal transmission of an interlayer between two glass panes

This clause considers the case of an interlayer between two glass panes. In this case, the interlayer/glass interfaces can be ignored as the refractive indices of the two materials are equivalent, resulting in $r = 0$ and $t = 1$ at such an interface. Interface 1 can be considered as the exterior interface of the first pane and interface 2 as the exterior interface of the second pane. Also, the parameters of these interfaces and the internal transmissions of both panes have previously been determined using procedures B.4.2.1 and B.4.2.2. For Equations (B.5), (B.6) and (B.7), the following can be considered:

$$\tau_1 = \tau_{G1}\tau_{LAM}\tau_{G2}$$

where

τ_1 = the internal transmission of the system;

τ_{G1} = the known internal transmission of the first glass pane;

τ_{LAM} = unknown internal transmission of the interlayer;

τ_{G2} = the known internal transmission of the second glass pane;

If the total transmittance, τ_T, of this system is measured, then the internal transmission of the system can be deduced using the quadratic equation given in Equation (B.20).

$$\tau_1 = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \qquad a = 1, \qquad b = \frac{t_1 t_2}{r_1^{'} r_2 \tau_T} \qquad c = -\frac{1}{r_1^{'} r_2} \tag{B.20}$$

Note that the positive root of the discriminant is used. The internal transmission is then determined by $\tau_{LAM} = \frac{\tau_1}{\tau_{G1}\tau_{G2}}$.

The procedure is illustrated in the following numerical example.

If the measured total transmission is:

$$\tau_T = 0{,}440312$$

and the previously determined values of the internal transmissions of the glass panes and the transmission and reflections values of the interfaces are:

$$\tau_{G1} = 0{,}970000$$
$$\tau_{G2} = 0{,}960000$$
$$t_1 = 0{,}600000,\ r_1 = 0{,}200000, \text{ and } r_1^{'} = 0{,}150000$$
$$t_2 = 0{,}850000,\ r_2 = 0{,}070000, \text{ and } r_2^{'} = 0{,}090000$$

Then the total internal transmission of the system is $\tau_1 = 0{,}856704$ resulting in $\tau_{LAM} = 0{,}920000$.

B.5 Systems with three interfaces

B.5.1 Calculations of the total transmission and reflections from the interface and media parameters

A system of three interfaces separated by two media is illustrated in Figure B.2.

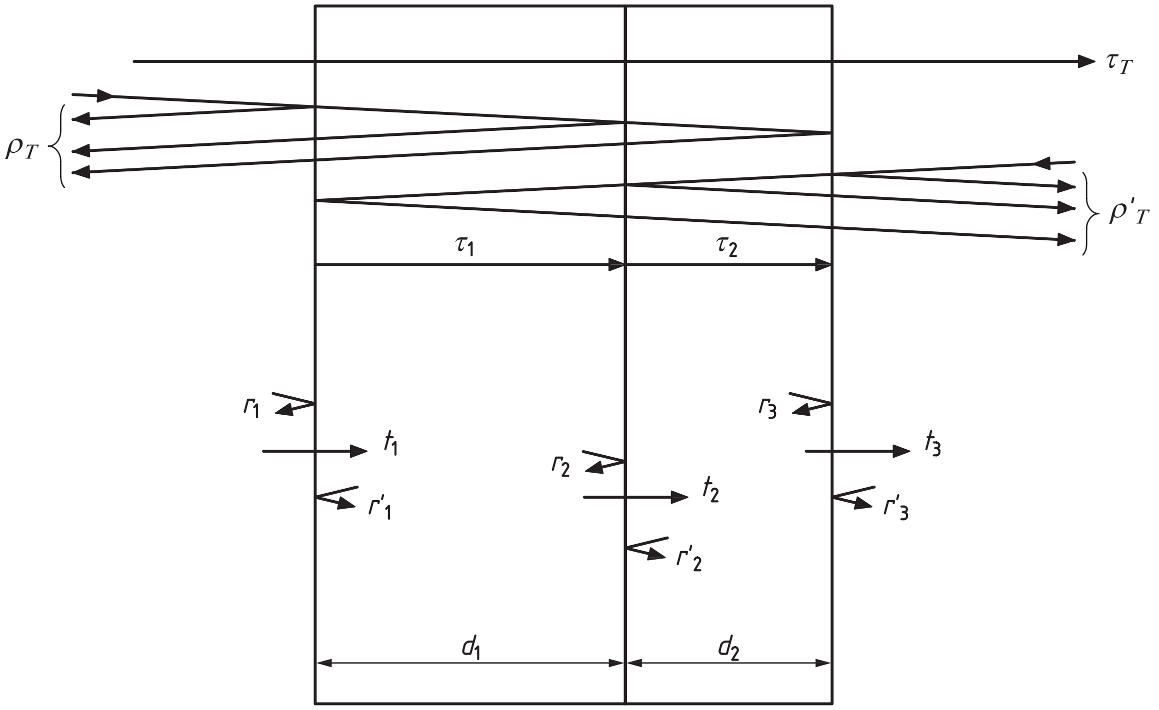


Figure B.2 — System of three interfaces separated by two media

In this system of three interfaces separated by two media the following can be defined:

τ_T = total transmission of the system including internal multiple reflections;

ρ_T = total reflection of light incident from the left of the system including internal multiple reflections;

ρ'_T = total reflection of light incident from the right of the system including internal multiple reflections;

t_1 = transmission of interface 1;

r_1 = reflection of interface 1 from light incident from the left;

r'_1 = reflection of interface 1 from light incident from the right;

t_2 = transmission of interface 2;

r_2 = reflection of interface 2 from light incident from the left;

r'_2 = reflection of interface 2 from light incident from the right;

t_3 = transmission of interface 3;

r_3 = reflection of interface 3 from light incident from the left;

r'_3 = reflection of interface 3 from light incident from the right;

τ_1 = internal transmission of medium 1;

d_1 = thickness of medium 1;

τ_2 = internal transmission of medium 2;

d_2 = thickness of medium 2;

The total transmission and reflections can be calculated from the interface and media parameters using Equations (B.21), (B.22) and (B.23).

$$\tau_T = \frac{t_1\tau_1 t_2\tau_2 t_3}{\left(1 - r'_1\tau_1^2 r_2\right) \times \left(1 - r'_2\tau_2^2 r_3\right) - r'_1\tau_1^2 t_2^2\tau_2^2 r_3} \tag{B.21}$$

$$\rho_T = r_1 + \frac{t_1^2\tau_1^2 r_2\left(1 - r'_2\tau_2^2 r_3\right) + t_1^2\tau_1^2 t_2^2\tau_2^2 r_3}{\left(1 - r'_1\tau_1^2 r_2\right) \times \left(1 - r'_2\tau_2^2 r_3\right) - r'_1\tau_1^2 t_2^2\tau_2^2 r_3} \tag{B.22}$$

$$\rho'_T = r'_3 + \frac{t_3^2\tau_2^2 r'_2\left(1 - r'_1\tau_1^2 r_2\right) + t_3^2\tau_1^2 t_2^2\tau_2^2 r'_1}{\left(1 - r'_1\tau_1^2 r_2\right) \times \left(1 - r'_2\tau_2^2 r_3\right) - r'_1\tau_1^2 t_2^2\tau_2^2 r_3} \tag{B.23}$$

The procedure is illustrated in the following numerical example:

Let

$$\begin{aligned} t_1 &= 0{,}600000,\ r_1 = 0{,}200000,\ \text{and } r'_1 = 0{,}150000 \\ \tau_1 &= 0{,}940000 \\ t_2 &= 0{,}850000,\ r_2 = 0{,}070000,\ \text{and } r'_2 = 0{,}090000 \\ \tau_2 &= 0{,}830000 \\ t_3 &= 0{,}660000,\ r_3 = 0{,}120000,\ \text{and } r'_3 = 0{,}180000 \end{aligned}$$

The total transmission and reflections of the system are:

$$\begin{aligned} \tau_T &= 0{,}269229 \\ \rho_T &= 0{,}242135 \\ \rho'_T &= 0{,}236891 \end{aligned}$$

B.5.2 Calculations of the interface and media parameters from the total transmission and reflections

The transmission and reflections of an interface between two media can be determined if the internal transmissions of the two media have previously been determined by procedure B.4.2.1 above and the parameters of the two external interfaces have also been previously determined by procedure B.4.2.1 or

B.4.2.2 above. If τ_T, ρ_T, and ρ_T' are the measured values of such a system then the parameters of the internal interface can be deduced by Equations (B.24), (B.25) and (B.26).

$$t_2 = \frac{t_1 \tau_T t_3}{\tau_1 \tau_2 ((t_1^2 - r_1 r_1')(t_3^2 - r_3 r_3') + \rho_T' r_3 (t_1^2 - r_1 r_1') + \rho_T r_1' (t_3^2 - r_3 r_3') - r_1' r_3 (\tau_T^2 - \rho_T \rho_T'))} \tag{B.24}$$

$$r_2 = \frac{(\rho_T - r_1)(t_3^2 - r_3 r_3') - r_3 (\tau_T^2 - \rho_T \rho_T') - r_3 r_1 \rho_T'}{\tau_1^2 ((t_1^2 - r_1 r_1')(t_3^2 - r_3 r_3') + \rho_T' r_3 (t_1^2 - r_1 r_1') + \rho_T r_1' (t_3^2 - r_3 r_3') - r_1' r_3 (\tau_T^2 - \rho_T \rho_T'))} \tag{B.25}$$

$$r_2' = \frac{(\rho_T' - r_3')(t_1^2 - r_1 r_1') - r_1' (\tau_T^2 - \rho_T \rho_T') - r_3' r_1' \rho_T}{\tau_2^2 ((t_1^2 - r_1 r_1')(t_3^2 - r_3 r_3') + \rho_T' r_3 (t_1^2 - r_1 r_1') + \rho_T r_1' (t_3^2 - r_3 r_3') - r_1' r_3 (\tau_T^2 - \rho_T \rho_T'))} \tag{B.26}$$

The procedure can be illustrated by the following numerical example (from above):

If the measured total transmission and reflection values are:

$$\begin{aligned} \tau_T &= 0{,}269229 \\ \rho_T &= 0{,}242135 \\ \rho_T' &= 0{,}236891 \end{aligned}$$

and the previously determined values of the internal transmission of the media and the transmission and reflections values of the first and third interfaces are:

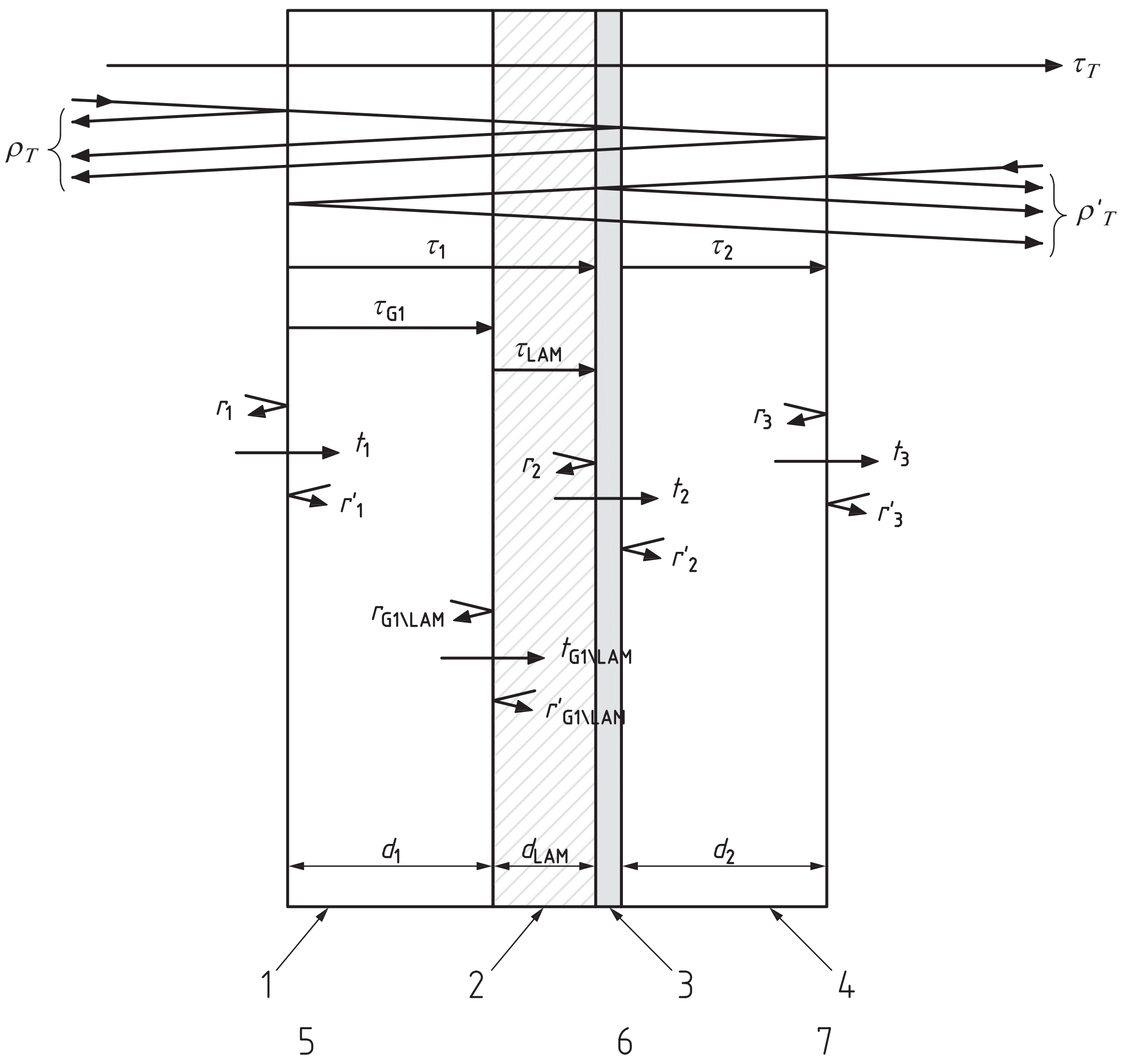
$$\begin{aligned} t_1 &= 0{,}600000,\ r_1 = 0{,}200000,\ \text{and}\ r_1' = 0{,}150000 \\ \tau_1 &= 0{,}940000 \\ \tau_2 &= 0{,}830000 \\ t_3 &= 0{,}660000,\ r_3 = 0{,}120000,\ \text{and}\ r_3' = 0{,}180000 \end{aligned}$$

Then Equations (B.24), (B.25), and (B.26) yield:

$$t_2 = 0{,}850000,\ r_2 = 0{,}070000,\ \text{and}\ r_2' = 0{,}090000$$

B.5.3 Example of Equations (B.24), (B.25), and (B.26): A coated layer between an interlayer and a glass pane

A laminated system with a coating layer between the interlayer and one of the glass panes is illustrated in Figure B.3.



Key

1	glass
2	interlayer
3	coating
4	glass
5	pane 1
6	layer
7	pane 2

Figure B.3 — Laminated system with a coating layer between the interlayer and one of the glass panes

It should be noted that the interlayer is fabricated with a refractive index approximately equal to refractive index of the glass panes. In this case, the uncoated interface between the interlayer and the glass pane will have zero reflection and a transmission of 1.0, i.e., for the Figure B3. above $r_{G1/LAM} = r'_{G1/LAM} = 0$ and $t_{G1/LAM} = 1.0$.

To determine the internal transmissions of the media and interface transmissions and reflections for all of the interfaces the procedure described below shall be followed:

- Determine the internal transmissions of the two glass panes, τ_{G1} and τ_{G2}, using procedure B.4.2.1 with uncoated single pane samples.

- Determine the internal transmission of the interlayer using procedure B.4.2.3 with a sample having the interlayer between two glass panes and without a coating between the interlayer and one of the glass panes.

- Determine the transmissions and reflections of the exterior interfaces (1 and 3), by using procedure B.4.2.1 for uncoated single pane samples or procedure B.4.2.2 for coated single pane samples.

- Finally, for the above case in Figure B.3 (coated interface between the interlayer and glass pane 2) let $\tau_1 = \tau_{G1}\tau_{LAM}$ and $\tau_2 = \tau_{G2}$. Procedure B.5.2 (i.e. Equations (B.24), (B.25), and (B.26)) shall be followed to determine the transmission and reflections of the internal coated interface. If the coated interface is between the interlayer and glass pane 1, let $\tau_1 = \tau_{G1}$ and $\tau_2 = \tau_{G2}\tau_{LAM}$ and the same procedure shall be used.

The procedure can be illustrated in the following numerical example (based on the system in Figure B.3):

If the measured total transmission and reflection values are:

$$\begin{aligned} \tau_T &= 0{,}269229 \\ \rho_T &= 0{,}242135 \\ \rho_T^{'} &= 0{,}236891 \end{aligned}$$

and the internal transmissions of the glass panes and the interlayer have been previously determined to be:

$$\begin{aligned} \tau_{G1} &= 0{,}980000 \\ \tau_{LAM} &= 0{,}959184 \\ \tau_{G2} &= 0{,}830000 \end{aligned}$$

Thus:

$$\begin{aligned} \tau_1 = \tau_{G1}\tau_{LAM} &= 0{,}940000 \\ \tau_2 = \tau_{G2} &= 0{,}830000 \end{aligned}$$

And the transmissions and reflections of the exterior interfaces have been previously determined to be:

$$\begin{aligned} t_1 &= 0{,}600000,\ r_1 = 0{,}200000,\text{ and } r_1^{'} = 0{,}150000 \\ t_3 &= 0{,}660000,\ r_3 = 0{,}120000,\text{ and } r_3^{'} = 0{,}180000 \end{aligned}$$

Then the transmission and reflections of the coated interior interface are:

$$t_2 = 0{,}850000,\ r_2 = 0{,}070000,\text{ and } r_2^{'} = 0{,}090000$$

B.6 Examples

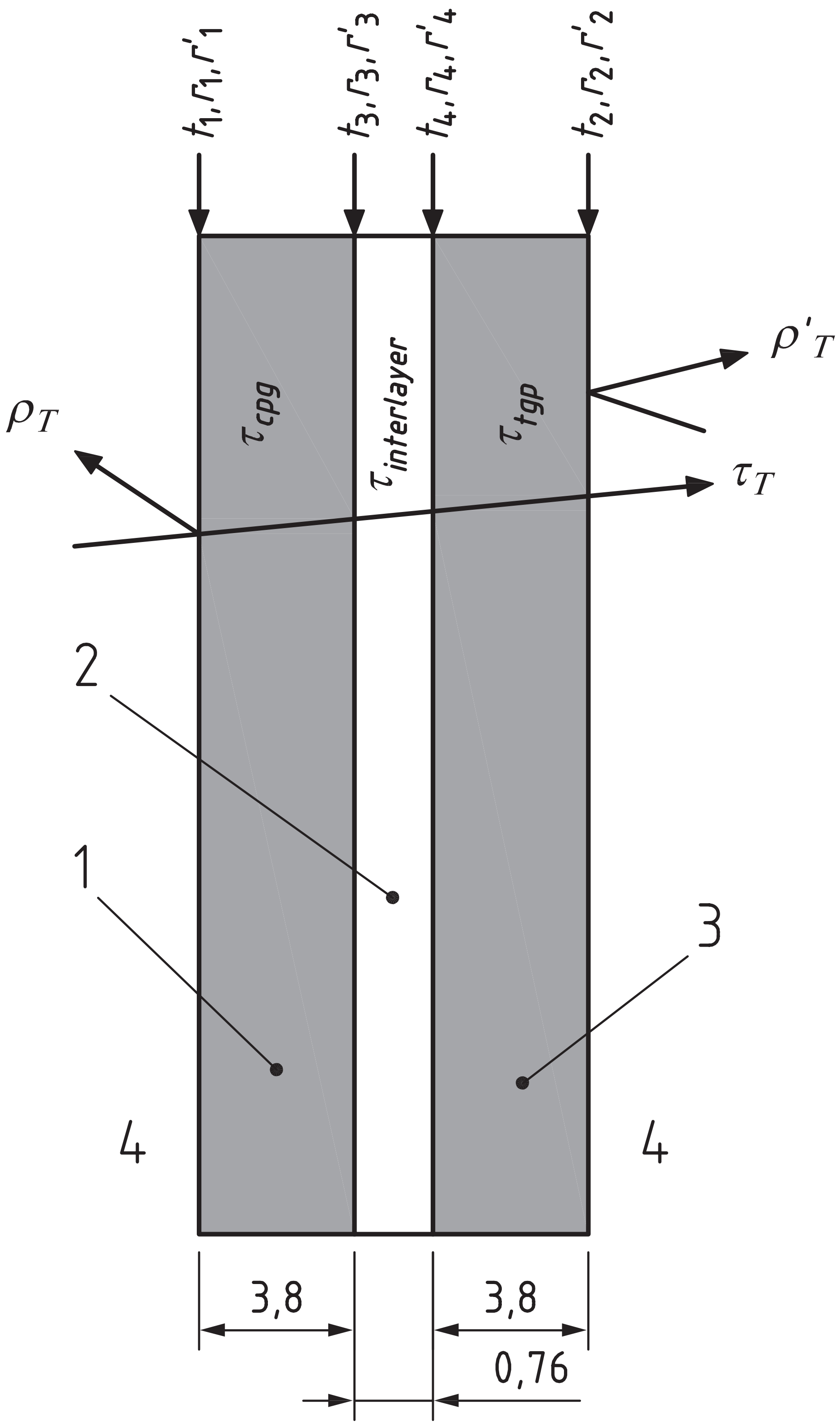
B.6.1 General

In this clause, two examples are given which demonstrate the application of the equations above. Example 1 (see B.6.2) covers a single medium between two interfaces. Example 1 (see B.6.3) covers an interlayer between two different glass panes with all surfaces uncoated. It illustrates the procedure in B.4 and the use of Equation (B.2), when the internal transmission is needed for glass thicknesses other that the thickness of the measured glass sample.

Another example could have been presented which would illustrate the case of requiring the internal transmission of an interlayer for a thickness other than the interlayer thickness of a measured sample. In this case the Equation (B.2) also applies and the calculations would be equivalent to those of different thicknesses of glass panes. The second example presented is an example of two media separated by three 3 interfaces in the form of an interlayer between two glass panes, with one of the surfaces coated between the interlayer and one of the glass panes. It illustrates the procedure detailed in B.5 and specifically addresses the calculations of such samples.

B.6.2 Example 1 - case of a simple laminated glass (uncoated)

Consider the case of the total properties (τ_T, ρ_T, ρ'_T) of a laminated glass sample (designated sample A) consisting of a 0,76 mm interlayer between a 3,8 mm clear float pane and a 3,8 mm tinted float pane with none of the interfaces of the glass panes coated. Suppose such a sample does not exist but its total properties need to be determined. Figure B.4 illustrates this sample combined with the parameters necessary to determine the total properties.



Key

1 clear glass pane (3,8 mm)
2 interlayer (0,76 mm)
3 tinted glass pane (3,8 mm)
4 air

Figure B.4 — Non existent sample A whose properties are to be determined

where

t_i, r_i, r_i' are the interface transmission and reflections of the indicated interface

τ_{cgp} is the internal transmission of the clear glass pane

τ_{tgp} is the internal transmission of the tinted glass pane

$\tau_{interlayer}$ is the internal transmission of the interlayer

Several parameters can be eliminated by noting the following properties of the interfaces:

1. The air/glass interfaces are uncoated. Equation (B.4) can be adopted in this case as follows:

   $r_1 = 1{,}000000 - t_1$ and $r_1' = r_1$

   $r_2 = 1{,}000000 - t_2$ and $r_2' = r_2$

2. The refractive indices of the both glass panes and interlayer are equivalent. This effectively means that these interfaces can be ignored or:

   $t_3 = 1{,}000000 - r_3$ and $r_3 = r'_3 = 0{,}00000$

   $t_4 = 1{,}000000$ and $r_4 = r'_4 = 0{,}000000$

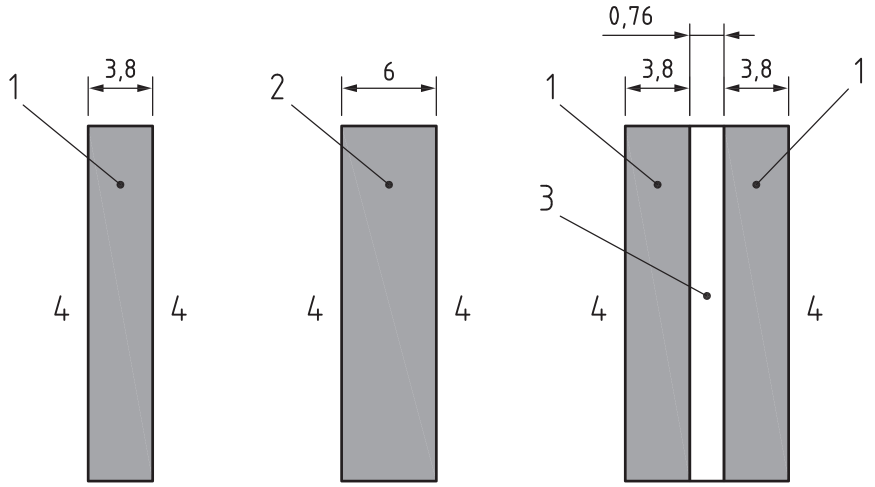
Noting that interfaces 3 and 4 can be ignored, the sample can be treated a as system of two interfaces separated by one medium (see Figure B.1). Using Equation (B.3) the total internal transmission can be given as:

$$\tau_{system} = \tau_{cgp}\tau_{interlayer}\tau_{tgp}$$

Where τ_{system} is the internal transmission of the entire sample A.

For a system of two interfaces separated by one medium, Equations (B.5), (B.6) and (B.7) can be used for calculations of the total luminous properties after resolving the unknown parameters ($r_1, r_2, \tau_{cgp}, \tau_{interlayer}$ and τ_{tgp}).

Although Sample A does not exist, Samples 1, 2 and 3 as described in Figure B.5 do exist.



a) b) c)

Key

1 clear glass pane (3,8 mm)
2 tinted glass pane (6,0 mm)
3 same interlayer (0,76 mm)
4 air

Figure B.5 — Structure of sample 1, 2 and 3

Measured values of the total transmissions and reflections of these samples, the unknown parameters to be determined, and the relevant equations are given in the Table B.1. Note that only the reflection from one side is given as all samples are uncoated and symmetric.

Table B.1 — Description of samples 1, 2 and 3

[41] Sample	[42] Unknown parameters to determine	[43] Equations to use	[44] Measured transmission and reflection values	
			[45] Transmission (τ_T)	[46] Reflection [47] (ρ_T)
[48] 1	[49] τ_{cgp}, r_1	[50] (B.8) and (B.9)	[51] 0,895300	[52] 0,074738
[53] 2	[54] τ_{tgp}, r_2	[55] (B.8), (B.9) and (B.2)	[56] 0,719548	[57] 0,062450
[58] 3	[59] $\tau_{interlayer}$	[60] (B.20)	[61] 0,824831	[62] Not needed

Using the corresponding equations with the measured values, the unknown parameters can be determined as indicated below:

- Sample 1

  Using Equations (B.8) and (B.9), the result is as follows:

  τ_{cgp} = 0,970000 and r_1 $=$ 0,040000

- Sample 2

Using Equations (B.8) and (B.9), the result is as follows:

$\tau_{tgp(6mm)} = 0.780000$ and $r_2 = 0.040000$

Equation (B.2) can be used to find the internal transmission of a 3.8 mm tinted glass pane from the internal transmission of the 6 mm tinted glass pane, resulting in:

$\tau_{tgp(3.8mm)} = 0.854397$

- Sample 3

The method outlined in B.4.2.3 can be used to determine the internal transmission of the interlayer. The exterior interface reflections and transmissions and the internal transmission of the clear glass sample have been determined using sample 1. Therefore, Equation (B.20) can be used to determine the internal transmission of sample 3, resulting in:

$\tau_{sample3}$ = 0,893855 (note that $\tau_{sample3}$ corresponds to τ_1 of Equation (B.20)).

Noting that $\tau_{sample3} = \tau_{cgp}\tau_{interlayer}\tau_{cgp}$ the internal transmission of the interlayer can finally be determined, resulting in:

$\tau_{interlayer}$ = 0,950000

All of the parameters needed to determine the total luminous properties of the original non existent sample A have been resolved.

In summary, the following have determined:

$r_1 = r_1'$ $=$ 0,040000 and t_1 $=$ 1,000000 – r_1 $=$ 0,960000

$r_2 = r_2'$ $=$ 0,40000 and t_2 $=$ 1,000000 – r_2 $=$ 0,960000

τ_{lgp} = 0,970000

τ_{lgp} = 0,854397

$\tau_{interlayer}$ = 0,950000

Thus the total internal transmittance of the non existent sample A is:

$$\tau_{system} = \tau_{cgp}\tau_{interlayer}\tau_{tgp} = 0.970000 \times 0.950000 \times 0.854397 = 0.787327$$

Equations (B.5), (B.6) and (B.7) thus become:

$$\tau_T = \frac{t_1 \tau_{system} t_2}{1 - r_1 \tau_{system}^2 r_2} = \frac{0.960000 \times 0.787327 \times 0.960000}{1 - 0.040000 \times 0.787327^2 \times 0.040000} = 0.726321$$

$$\rho_T = r_1 + \frac{t_1^2 \tau_{system}^2 r_2}{1 - r_1 \tau_{system}^2 r_2} = 0.040000 + \frac{0.960000^2 \times 0.787327^2 \times 0.040000}{1 - 0.040000 \times 0.787327^2 \times 0.040000} = 0.062874$$

$$\rho_T' = r_2 + \frac{r_1 \tau_{system}^2 t_2^2}{1 - r_1 \tau_{system}^2 r_2} = 0.062874$$

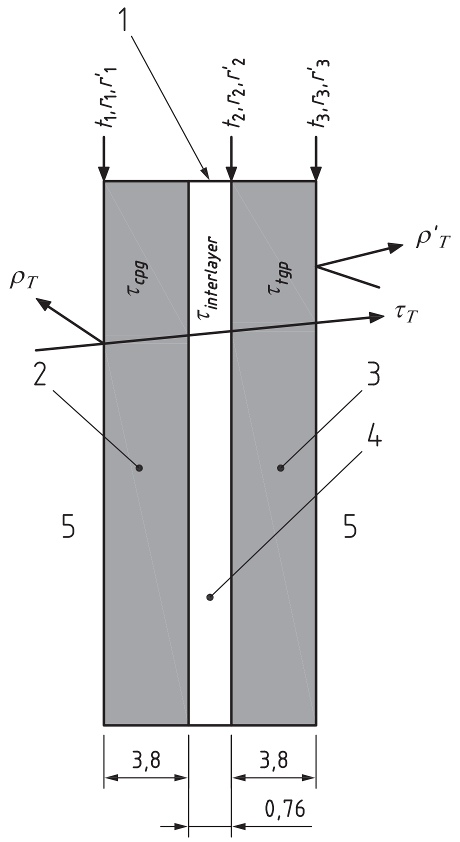
Note that note that τ_{system} corresponds to τ_1 of Equations (B.5), (B.6), (B.7).

Thus, for the original non existent sample A:

$$\begin{aligned} \tau_T &= 0{,}726321 \\ \rho_T &= \rho_T' = 0{,}062874 \end{aligned}$$

B.6.3 Example 2: Case of a laminated glass with an absorbing coating between the interlayer and the second glass pane with the external surfaces uncoated

For this example the same system as described in example 1 can be used, but with an absorbing coating between the interlayer and the tinted glass pane, i.e., a 3,8 mm clear float glass pane, a 0,76 mm interlayer, an absorbing coating an finally a 3,8 mm tinted glass pane. Again, suppose this sample does not physically exist, but its total luminous properties are required. This sample can be designated as sample B (see Figure B.6). Note, all parameters have been previously determined using samples 1, 2, and 3 with the exceptions of t_2, r_2 and r_2'.

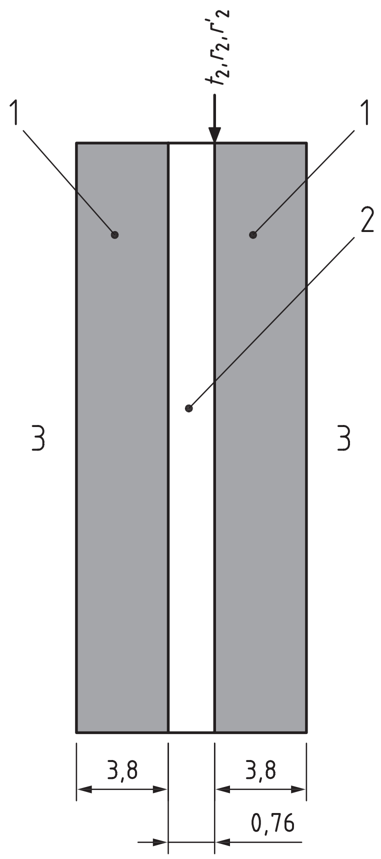


Key

1 coated interface
2 clear glass pane (3,8 mm)
3 tinted glass pane (3,8 mm)
4 interlayer (0,76 mm)
5 air

Figure B.6 — Non existent sample B whose properties are to be determined

To determine t_2, r_2 and r_2' there physically exists sample 4 with the same absorbing film properties (interface 2) as sample B. It is described in Figure B.7.



Key

1	clear glass pane (3,8 mm)
2	interlayer (0,76 mm)
3	air

Figure B.7 — Description of sample 4

For the same reason as sample A, the interface between the interlayer and the first glass pane can be ignored making both sample B and sample 4 cases of 2 media between 3 interfaces as described in B.5 and detailed in B.5.3.

Measured values of the total transmissions and reflections, the unknown parameters to be determined, and the relevant equations are given for sample 4 in the Table B.2.

Table B.2 — Description of sample 4

[73] Sample	[74] Unknown parameters to determine	[75] Equations to use	[76] Measured transmission and reflection values		
			[77] Transmission (τ_T)	[78] Front Reflection [79] (ρ_T)	[80] Back Reflection [81] (ρ'_T)
[82] 4	[83] t_2, r_2 and r'_2	[84] (B.24), (B.25), and (B.26)	[85] 0,649055	[86] 0,168273	[87] 0,162711

Using Equations (B.24), (B.25), and (B.26) the following can be found:

$$\begin{aligned} t_2 &= 0{,}780000 \\ r_2 &= 0{,}140000 \\ r'_2 &= 0{,}120000 \end{aligned}$$

Note that the terms τ_1 and τ_2 were replaced with $\tau_{cgp} \times \tau_{interlayer}$ and τ_{cgp} respectively. Also, the exterior interface 3 of sample 4 is equivalent to exterior interface 2 of sample A.

In summary, the following parameters are known:

$r_1 = r'_1 = 0{,}40000$ and $t_1 = 1{,}000000 - r_1 = 0{,}960000$

$r_2 = 0{,}140000$, $r'_2 = 0{,}120000$, and $t_2 = 0{,}780000$

$r_3 = r'_3 = 0{,}040000$ and $t_3 = 1{,}000000 - r_3 = 0{,}960000$

$\tau_{lgp} = 0{,}970000$

$\tau_{lgp} = 0{,}854397$

$\tau_{interlayer} = 0{,}950000$

The total properties of sample B can be determined using Equations (B.21), (B.22), and (B.23). Noting that the terms τ_1 and τ_2 were replaced with $\tau_{cgp} \times \tau_{interlayer}$ and τ_{lgp} respectively, this results in:

$$\begin{aligned} \tau_T &= 0{,}571020 \\ \rho_T &= 0{,}164180 \\ \rho'_T &= 0{,}135092 \end{aligned}$$

Annex C
(informative)

Procedure for calculation of the spectral characteristics of screen printed glass

This Annex provides general guidance on calculation of the spectral characteristics of screen printed glass, i.e. glass to which ceramic ink finish has been applied to one surface.

NOTE In some countries, screen printed glass may be referred to as enamelled or fritted glass.

The amount of area covered by the finish is calculated as a fraction of the whole surface area by measuring suitable geometric features of the finish (e.g. lines, dots, mesh, etc.). Separate spectral measurements are undertaken on an area of the glass with and without the finish. Finally, the spectral characteristics are determined by average weighting based on the fraction of the surface covered by the finish.

For finishes with complex geometries, it may be possible to determine the fraction of the surface covered by the finish by using appropriate computer software to count the number of black and white pixels in a black and white photograph of the glass.

Annex D
(informative)

Example of calculation of colour rendering index

Example of the calculation of the colour rendering index of daylight defined by illuminant D65 which has been transmitted through a typical absorbing glass.

Step 1: Calculate the trichromatic components for illuminant D65 through the sample.

An example of the spectral transmittance data for a typical green absorbing glass is given in Table D.1.

The calculated components are determined from Equations (26), (27), (28), (32), (33), (38) and (39).

X_t	766,143
Y_t	814,400
Z_t	811,715
------------------------	
u_t	0,199
v_t	0,317
------------------------	
c_t	1,993
d_t	2,054

Table D.1 — Spectral transmittance for a typical green absorbing glass from 380 nm to 780 nm

λ nm	Transmittance $\tau(\lambda)$
380	0,592
390	0,652
400	0,678
410	0,683
420	0,684
430	0,687
440	0,690
450	0,699
460	0,709
470	0,717
480	0,726
490	0,735
500	0,744
510	0,752
520	0,760
530	0,766
540	0,773
550	0,779
560	0,782
570	0,784
580	0,784
590	0,784
600	0,783
610	0,779
620	0,776
630	0,771
640	0,766
650	0,761
660	0,755
670	0,749
680	0,743
690	0,734
700	0,726
710	0,717
720	0,707
730	0,698
740	0,686
750	0,676
760	0,665
770	0,654
780	0,642

Step 2: Calculate for each of the eight test colours the following terms sequentially in accordance with the formulae in 4.6.

The calculated components are reported in Table D.2.

Table D.2 — Calculated components

	Test colour number							
Component	1	2	3	4	5	6	7	8
$X_{t,i}$	267,531	224,130	195,584	165,682	200,141	223,849	265,824	302,177
$Y_{t,i}$	243,155	236,285	249,106	239,959	250,449	241,346	238,572	255,081
$Z_{t,i}$	182,875	111,807	74,613	159,929	301,437	430,649	394,758	337,279
$u_{t,i}$	0,240	0,218	0,188	0,156	0,165	0,174	0,211	0,235
$v_{t,i}$	0,327	0,345	0,360	0,339	0,309	0,282	0,285	0,298
$c_{t,i}$	1,504	0,946	0,599	1,333	2,407	3,569	3,309	2,645
$d_{t,i}$	1,858	1,941	2,056	2,217	2,226	2,225	2,027	1,895
$u'_{t,i}$	0,238	0,217	0,186	0,155	0,164	0,175	0,211	0,234
$v'_{t,i}$	0,323	0,343	0,358	0,336	0,304	0,275	0,278	0,292
$W^*_{t,i}$	60,557	59,820	61,185	60,216	61,325	60,364	60,067	61,805
$U^*_{t,i}$	31,813	14,725	-9,162	-33,531	-26,607	-18,101	10,321	29,149
$V^*_{t,i}$	8,554	23,845	36,379	18,325	-6,805	-29,044	-26,508	-16,109

Table D.2 *(continued)*

	Test colour number							
Component	1	2	3	4	5	6	7	8
$-E_i$	0,196	0,510	0,834	0,398	0,343	0,757	0,556	0,392
R_i	99,100	97,653	96,166	98,169	98,422	96,519	97,443	98,195
NOTE Some small discrepancies in the calculated values of the above terms may arise according to the number of decimals used in the calculations. However, the influence on the final value is negligible.								

The general colour rendering index R_a is given by:

$R_a = \frac{1}{8}\sum_{i=1}^{8} R_i = 97,708$ to be rounded as 98.

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