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Introduction

This draft standard is based on national and international discussions. Your comments on this draft are invited and will assist in the preparation of the consequent standard.

For international standards, comments will be reviewed by the relevant UK national committee before sending the consensus UK vote and comments to the international committee, which will then decide appropriate action. If the international standard is approved, it is usual for the text to be published as a British Standard.

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Please indicate whether you consider the UK should submit a negative (with supporting technical reasons) or positive vote on this draft. Please indicate if you are aware of any reason why this draft standard should not be published as a British Standard.

Submission of Comments

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Template for comments and secretariat observations

Date: xx/xx/20xx	Document: ISO/DIS xxxx
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1	2	(3)	4	5	(6)	7
MB	Clause No./ Subclause No./Annex (e.g. 3.1)	Paragraph/ Figure/Table/Note	Type of comment	Comment (justification for change) by the MB	Proposed change by the MB	Secretariat observations on each comment submitted
	3.1	Definition 1	ed	Definition is ambiguous and needs clarifying.	Amend to read '...so that the mains connector to which no connection...'	
	6.4	Paragraph 2	te	The use of the UV photometer as an alternative cannot be supported as serious problems have been encountered in its use in the UK.	Delete reference to UV photometer.	



DRAFT
International
Standard

ISO/DIS 15099

**Thermal performance of windows,
doors and shading devices —
Detailed calculations**

*Performance thermique des fenêtres, portes et stores — Calculs
détaillés*

ICS: 91.120.10; 91.060.50

ISO/TC 163/SC 2

Secretariat: **SN**

Voting begins on:
2024-02-07

Voting terminates on:
2024-05-01

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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.

This edition includes the following significant changes compared with the previous edition:

- 1 h): addition of clear active window building integrated photo voltaic(BIPV)
- 2: additional reference to ISO TS 18178 and eight IEC standards related to design qualifications and module safety in Normative References
- [4.1.5](#): new clause with schematic covering clear active window BIPV
- [8.7](#): addition of **refraction of light spectra to solar collectors and energy production**
- [8.7](#) new formulas for calculations related to the energy harvesting efficiency and production

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 15099 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*.

Introduction

This International Standard describes a procedure for calculating indices of merit of many window and door products. The method provided in this International Standard allows the user to determine total window and door product indices of merit, viz thermal transmittance, total solar energy transmittance and visible light transmittance.

The procedures give the actual thermal performance of fenestration products for use in building energy analysis and for the evaluation of products in specific building applications. These procedures can also be used to produce data to compare products by using the standardized boundary conditions given either in this International Standard or taken from the appropriate International or National Standards (e.g., ISO 12567-1, ISO 10292, ISO 9050). This International Standard is also intended as a reference document for the description of models used in computer programs for detailed calculation of the thermal and optical transmission properties of window and door systems.

This International Standard gives detailed models for thermal and optical transmission in windows. These detailed models are necessary in many types of windows to get agreement between calculations and tests.

Traditionally, windows have been characterized by separately calculating the “dark” or “night-time” thermal transmittance and the solar energy transmittance through the fenestration system. The thermal transmittance without the effect of solar radiation is calculated using the procedures given in ISO 10292 (for the vision portion) and the total solar energy transmittance, without taking into account the actual temperatures of the various panes, is obtained using ISO 9050. These calculations require the use of reference conditions that are not representative of actual conditions. In this International Standard the energy balance equations are set up for every glazing layer taking into account the solar absorption and actual temperatures. From these energy balance equations, the temperatures of the individual layers and gaps are determined. This is the only standard that takes into account these complex interactions. This more detailed analysis provides results that can then be expressed as thermal transmittance and τ_s -values and these values can differ from the results of simpler models.

Individual indices of merit obtained using fixed reference boundary conditions are useful for comparing products. However, the approach taken is the only way of calculating the energy performance of window systems for other environmental conditions including those conditions that may be encountered during hot box measurements.

Finally it must be emphasized that this International Standard is intended for use in computer programs. It was never intended as a “simplified calculation” procedure. Simplified methods are provided in other International Standards. It is essential that these programs produce consistent values and that they are based on a sound standard methodology. Although more complicated than the formulae used in the simplified standards, the formulae used in this International Standard are entirely appropriate for their intended use.

Thermal performance of windows, doors and shading devices — Detailed calculations

1 Scope

This International Standard specifies detailed calculation procedures for determining the thermal and optical transmission properties (e.g., thermal transmittance, total solar energy transmittance) of window and door systems based on the most up-to-date algorithms and methods, and the relevant solar and thermal properties of all components.

Products covered by this International Standard include windows and doors incorporating:

- a) single and multiple glazed fenestration products with or without solar reflective, low-emissivity coatings and suspended plastic films;
- b) glazing systems with pane spacing of any width containing gases or mixtures of gases;
- c) metallic or non-metallic spacers;
- d) frames of any material and design;
- e) fenestration products tilted at any angle;
- f) shading devices;
- g) projecting products;
- h) clear active window building integrated photo voltaic (BIPV).

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 7345, *Thermal insulation — Physical quantities and definitions*

ISO 8301, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Heat flow meter apparatus*

ISO 8302, *Thermal insulation — Determination of steady-state thermal resistance and related properties — Guarded hot plate apparatus*

ISO 9050, *Glass in building — Determination of light transmittance, solar direct transmittance, total solar energy transmittance, ultraviolet transmittance and related glazing factors*

ISO 9288, *Thermal insulation — Heat transfer by radiation — Physical quantities and definitions*

ISO 9845-1, *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 10077-2:2003, *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance — Part 2: Numerical method for frames*

ISO 10211-1, *Thermal bridges in building construction — Heat flows and surface temperatures, Part 1: General calculation methods*

ISO/CIE 10526:1999, *CIE standard Illuminants for colorimetry*

ISO/CIE 10527, *CIE standard colorimetric observers*

ISO 12567-1, *Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method — Part 1: Complete windows and doors*

ISO 14617-1:2005, *“Graphic symbols for diagrams-Part1”*

ISO/IEC 17025, *General requirements for the competence of testing and calibration laboratories*

ISO/TS 18178, *Glass in building — Laminated solar photovoltaic glass for use in buildings*

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

IEC 61215-1, *Terrestrial photovoltaic (PV) modules – Design qualification and type approval – Part 1: Test requirements*

IEC 61215-1-1, *Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-1: Special requirements for testing of crystalline silicon photovoltaic (PV) modules*

IEC 61215-1-2, *Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-2: Special requirements for testing of thin-film Cadmium Telluride (CdTe) based photovoltaic (PV) modules*

IEC 61215-1-3, *Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-3: Special requirements for testing of thin-film amorphous silicon based photovoltaic (PV) modules*

IEC 61215-1-4, *Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 1-4: Special requirements for testing of thin-film Cu(In,Ga)(S,Se)₂ based photovoltaic (PV) modules*

IEC 61215-2, *Terrestrial photovoltaic (PV) modules - Design qualification and type approval - Part 2: Test procedures*

IEC 61730-1, *Photovoltaic (PV) module safety qualification - Part 1: Requirements for construction*

IEC 61730-2, *Photovoltaic (PV) module safety qualification - Part 2: Requirements for testing*

IEC 63092-1:2020, *Photovoltaics in buildings - Part 1: Requirements for building-integrated photovoltaic modules*

3 Symbols

3.1 General

Symbols and units used are in accordance with ISO 7345 and ISO 9288. The terms, which are specific to this International Standard, are listed in [Table 1](#).

3.2 Symbols and units

Table 1 — Terms with their symbols and units

Symbol	Term	Unit
A	Area	m ²
A_i	portion of absorbed solar energy by the i th glazing layer	1
A_R	aspect ratio	1
B	width (breadth) of a groove or slit	mm
C_p	specific heat capacity at constant pressure	J/(kg·K)
D	Thickness	m
D_g	thickness of glazing cavity	m

Table 1 (continued)

Symbol	Term	Unit
E	Irradiance	W/m ²
$E_s(\lambda)$	solar spectral irradiance function (see ISO 9845-1)	1
$E_v(\lambda)$	colorimetric illuminance (CIE D65 function in ISO/CIE 10526:1999)	lx
G	acceleration due to gravity	m/s ²
G	parameter used in the calculation of convective heat transfer coefficients; see Equation (48)	1
H	surface coefficient of heat transfer	W/(m ² ·K)
H	height of glazing cavity	m
I	total density of heat flow rate of incident solar radiation	W/m ²
J	Radiosity	W/m ²
$I_i^+(\lambda)$ $I_i^-(\lambda)$	spectral heat flow rate of radiant solar energy between i th and $i + 1$ th glazing layers travelling in the external (+) or internal (−) direction	W
$\hat{M}$	molecular mass	Mole
N	number of glazings + 2	1
Nu	Nusselt number	1
P	Pressure	Pa
Q	density of heat flow rate	W/m ²
R	reflectance: portion of incident radiation reflected such that the angle of reflection is equal to the angle of incidence	1
R	thermal resistance	m ² ·K/W
$R(\lambda)$	photopic response of the eye (see ISO/CIE 10527)	
$\mathfrak{R}$	universal gas constant	J/(kmol·K)
Ra	Rayleigh number	1
Ra_x	Rayleigh number based on length dimension x	1
S_i	density of heat flow rate of absorbed solar radiation at i th glazing layer	W/m ²
T_{perp}	largest dimension of frame cavity perpendicular to heat flow	M
T	thermodynamic temperature	K
ΔT_i	temperature drop across i th glazing cavity, $\Delta T_i = T_{f,i} - T_{b,i+1} $	K
U	air velocity near a surface	m/s
U	thermal transmittance	W/(m ² ·K)
V	free-stream air speed near window, mean air velocity in a gap	m/s
x, y	dimensions in a Cartesian co-ordinate system	1
Z	pressure loss factor	1
α	Absorption	1
β	thermal expansion coefficient of fill gas	K ^{−1}
ε	total hemispherical emissivity	1
γ	Angle	°
θ	Temperature	°C
σ	Stefan-Boltzmann constant, $5,669\,3 \times 10^{-8}$	W/(m ² ·K ⁴)
λ	thermal conductivity	W/(m·K)
λ_w	Wavelength	M
μ	dynamic viscosity	Pa·s
ρ	Density	kg/m ³
τ	Transmittance	1

Table 1 (continued)

Symbol	Term	Unit
τ_s	total solar energy transmittance: the portion of radiant solar energy incident on the projected area of a fenestration product or component that becomes heat gain in the internal conditioned space	1
ϕ	parameter used in the calculation of viscosity and of thermal conductivity; see Equations (62) and (67)	1
φ	function used in the calculation of heat transfer; see Equation (112)	1
Φ	heat flow rate	W
Ψ	linear thermal transmittance	W/(m·K)

3.3 Subscripts

The subscripts given in [Table 2](#) shall be applied.

Table 2 — Subscripts and meanings

Subscript	Meaning
Ai	Air
Av	Average
B	Backward
Bo	bottom of a gap
Cc	condition on the cold side
Cdv	conduction/convection (unvented)
Cg	centre of glass
Ch	condition on the hot (warm) side
Cr	Critical
Cv	Convection
De	divider edge glass
Dif	Diffuse
Dir	Direct
Div	Divider
Eff	Effective
Eg	edge of glass
Eq	Equivalent
Ex	External
F	Frame
Fr	frame (using the alternative approach)
Ft	Front
Gv	glass or vision portion
Ht	Hot
Hz	Horizontal
I	Counter
Int	Internal
Inl	inlet of a gap
J	Counter
M	Mean
Mix	Mixture

Table 2 (continued)

Subscript	Meaning
<i>N</i>	Counter
<i>Ne</i>	environmental (external)
<i>Ni</i>	environmental (internal)
<i>Out</i>	outlet of a gap
<i>P</i>	Panel
<i>R</i>	radiation or radiant
<i>Red</i>	reduced radiation
<i>S</i>	Surface
<i>Sc</i>	Source
<i>Sk</i>	Sink
<i>Sl</i>	Solar
<i>T</i>	Total
<i>Tp</i>	top of a gap
<i>V</i>	number of gases in a gas mixture
<i>V</i>	Vertical
<i>Z</i>	at distance <i>z</i>
Ψ	Perimeter
<i>2D</i>	Coupling

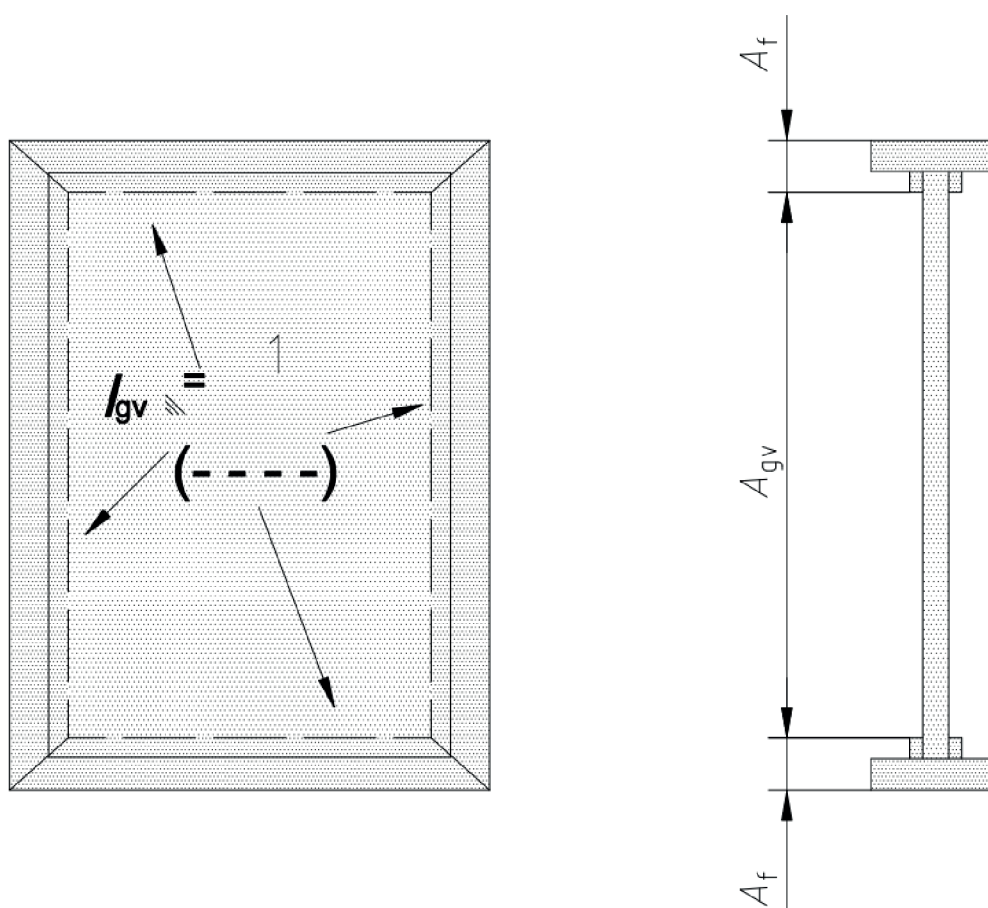
4 Determination of total window, door and clear active window BIPV system properties

4.1 Thermal transmittance

4.1.1 General

This International Standard presents procedures by which detailed computations can be used to determine the thermal transmission properties of various product components, which are then used to determine the thermal transmission properties of the total product. Where national standards allow, test procedures may be used to determine component and total product properties.

The total properties for window and door products are calculated by combining the various component properties weighted by either their respective projected areas or visible perimeter. The total properties are each based on total projected area occupied by the product, A_t . The projected component areas and the visible perimeter are shown in [Figure 1](#).



Key

1 perimeter length at sight line - - - -

Figure 1 — Schematic diagram showing the window projected areas and vision perimeter

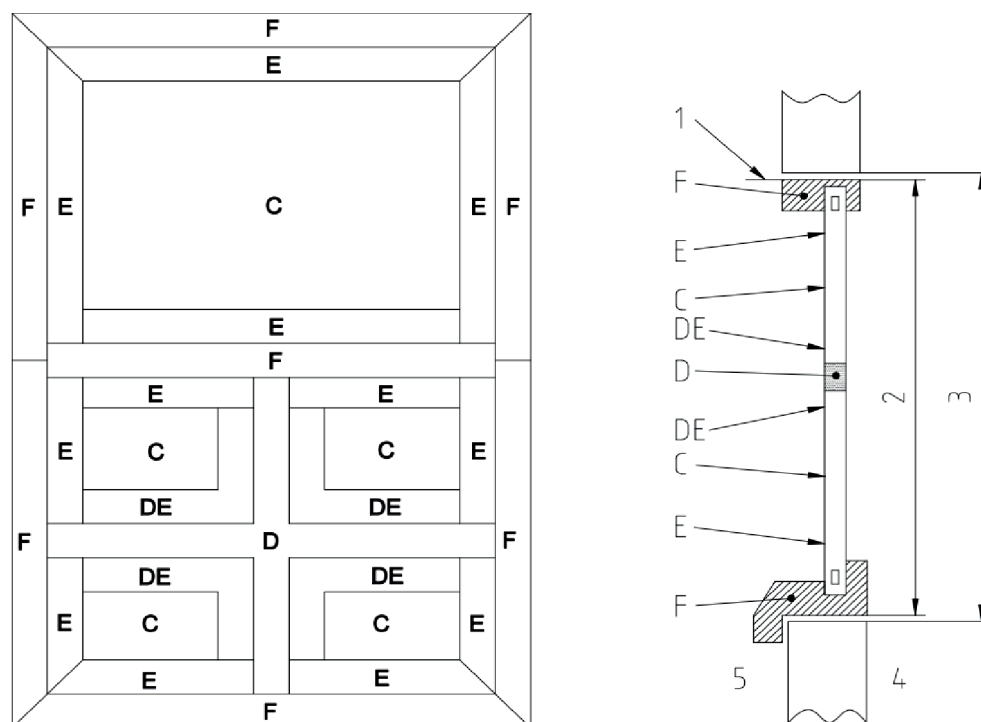
[Clause 4](#) describes the procedure for calculating thermal transmittance, total solar transmittance and visible transmittance for the complete product. [4.1](#) describes the procedure for calculating thermal transmittance. The effect of three-dimensional heat transfer in frames and glazing units is not considered. [4.1.4](#) describes an alternative procedure for calculating edge of glass and frame thermal indices U_{de} , U_{eg} , U_t and U_{fr} , which are used in area-based calculations. [Clause 5](#) describes the procedure for calculating the required centre-glass properties τ_{sgv} and τ_{gv} . [Clause 6](#) describes the procedure for calculating the linear thermal transmittance, Ψ , which accounts for the interaction between frame and glazing or opaque panel. [Clause 7](#) contains the procedure for dealing with shading devices and ventilated windows. [Clause 8](#) describes the procedure for determining and applying boundary conditions. The thermal transmittance of the fenestration product is given by:

$$U_t = \frac{\sum A_{gv} U_{gv} + \sum A_f U_f + \sum l_{\Psi} \Psi}{A_t} \quad (1)$$

where A_{gv} and A_f are the projected vision area and frame area, respectively. The length of the vision area perimeter is l_{Ψ} , and Ψ is a linear thermal transmittance that accounts for the interaction between frame and glazing or the interaction between frame and opaque panel (e.g., a spandrel panel).

The summations included in [Equation \(1\)](#) are used to account for the various sections of one particular component type; e.g. several values of A_f are needed to sum the contributions of different values of U_f corresponding to sill, head, dividers and side jambs.

Figure 2 illustrates the division into components for the alternative approach described in 4.1.4, in which the edge-of-glass and divider-edge areas are 63,5 mm (2,5 in) wide. The sum of all component areas equals the total projected fenestration product area.



Key

C	centre-of-glass	1	installation clearance
E	edge-of-glass	2	projected area
F	frame	3	rough opening
D	divider	4	interior
DE	divider-edge	5	exterior

Figure 2 — Centre-of-glass, edge-of-glass, divider, divider-edge, and frame areas for a typical fenestration product

4.1.2 Glazed area thermal transmittance

The thermal transmittance can be found by simulating a single environmental condition involving internal/external temperature difference, with or without incident solar radiation. Without solar radiation, the thermal transmittance is the reciprocal of the total thermal resistance.

$$U_{gv} = \frac{1}{R_t} \quad (2)$$

and when solar radiation is considered, then:

$$U_{gv} = \frac{q_{\text{int}}(I_s = 0)}{T_{\text{ni}} - T_{\text{ne}}} \quad (3)$$

where $q_{\text{int}}(I_s = 0)$ is the net density of heat flow rate through the window or door system to the internal environment for the specified conditions, but without incident solar radiation, in W/m^2 . The condition “without solar radiation” is used because all effects on the thermal resistances due to incident solar radiation are incorporated in the total solar energy transmittance or τ_s -value [see Equation (14)], and T_{ni} and T_{ne} are the environmental temperatures, as defined in Equation (7).

R_t is found by summing the thermal resistances at the external and internal boundaries, and thermal the resistances of glazing cavities and glazing layers. See [Figure 3](#).

$$R_t = \frac{1}{h_{ex}} + \sum_{i=2}^n R_i + \sum_{i=1}^n R_{gv,i} + \frac{1}{h_{int}} \quad (4)$$

where the thermal resistance of the i th glazing is:

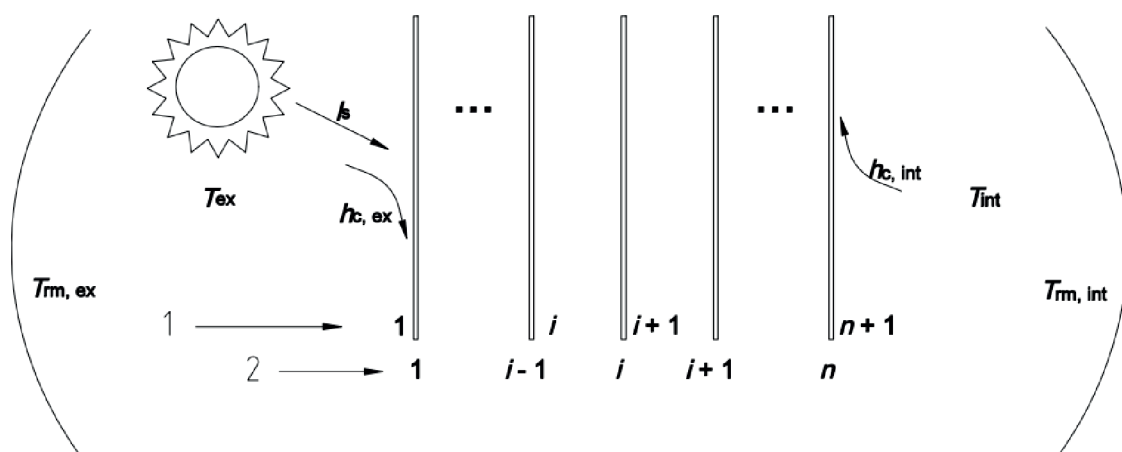
$$R_{gv,i} = \frac{t_{gv,i}}{\lambda_{gv,i}} \quad (5)$$

and the thermal resistance of the i th space, where the first space is external environment, the last space is internal environment and the spaces in between are glazing cavities, (see [Figure 3](#)):

$$R_i = \frac{T_{f,i} - T_{b,i-1}}{q_i} \quad (6)$$

where $T_{f,i}$ and $T_{b,i-1}$ are the external and internal facing surface temperature of the i th glazing layer.

The environmental temperature [as defined in [Equation \(7\)](#)] is a weighted average of the ambient air temperature and the mean radiant temperature, T_{rm} , which is determined for external and internal environment boundary conditions (see boundary conditions in [8.4.1](#)).



Key

- 1 gap
- 2 glazing

Figure 3 — Numbering system for glazing system layers

The environmental temperature, T_n , is:

$$T_n = \frac{h_{cv} T_{ai} + h_r T_{rm}}{h_{cv} + h_r} \quad (7)$$

where h_{cv} and h_r are determined according to the procedure given in [Clause 8](#).

4.1.3 Frame area/edge-glass thermal indices

In order to convert the results of a two-dimensional numerical analysis to thermal transmittances, it is necessary to record the rate of heat transfer from the internal environment to the frame and edge-glass

surfaces (in the absence of solar radiation). The linear thermal transmittance, Ψ , values and frame thermal transmittances shall be calculated according to the following equations.

$$\Psi = L^{2D} - U_f l_f - U_{gv} l_{gv} \quad (8)$$

where L^{2D} is thermal coupling coefficient determined from the actual fenestration system.

$$U_f = \frac{L_p^{2D} - U_p l_p}{l_f} \quad (9)$$

where

L_p^{2D} is thermal coupling coefficient determined from the frame/panel insert system;

U_p is the thermal transmittance of foam insert;

l_p is the internal side exposed length of foam insert (minimum 100 mm);

l_f is the internal side projected length of the frame section;

l_{gv} is the internal side projected length of the glass section (see Figures C.1 and C.2 of ISO 10077-2:2003, for further details on the definition of l_{fr} and l_p).

The detailed procedure for determining L^{2D} is also given in ISO 10211-1

4.1.4 Alternative approach (see [Figure 2](#))

An alternative method is available for calculating frame thermal transmittance, U_{fr} . Using this method it is unnecessary to determine the linear thermal transmittance, Ψ . Instead, the glass area, A_{gv} , is divided into centre-glass area, A_c , plus edge-glass area, A_e , and one additional thermal transmittance, U_{eg} , is used to characterize the edge-glass area. If dividers are present then divider area, A_{div} and divider thermal transmittance, U_{div} are calculated, as well as corresponding divider edge area, A_{de} and thermal transmittance, U_{de} . The following equation shall be used to calculate the total thermal transmittance:

$$U_t = \frac{\sum U_{cg} A_c + \sum U_{fr} A_f + \sum U_{eg} A_e + \sum U_{div} A_{div} + \sum U_{de} A_{de}}{A_t} \quad (10)$$

where U_{fr} and U_{eg} can be determined from the following equations:

$$U_{fr} = \frac{\Phi_{fr}}{l_f (T_{ni} - T_{ne})} \quad (11)$$

$$U_{eg} = \frac{\Phi_{eg}}{l_{eg} (T_{ni} - T_{ne})} \quad (12)$$

and where l_f is projected length of frame area and l_{eg} is the length of edge of glass area and is equal to 63,5 mm. These lengths are measured on the internal side. The quantities Φ_{fr} and Φ_{eg} are heat flow rates through frame and edge-glass areas (internal surfaces), respectively, including the effect of glass and spacer, and both are expressed per length of frame or edge-glass. The calculations shall be performed for each combination of frame and glazing with different spacer bars.

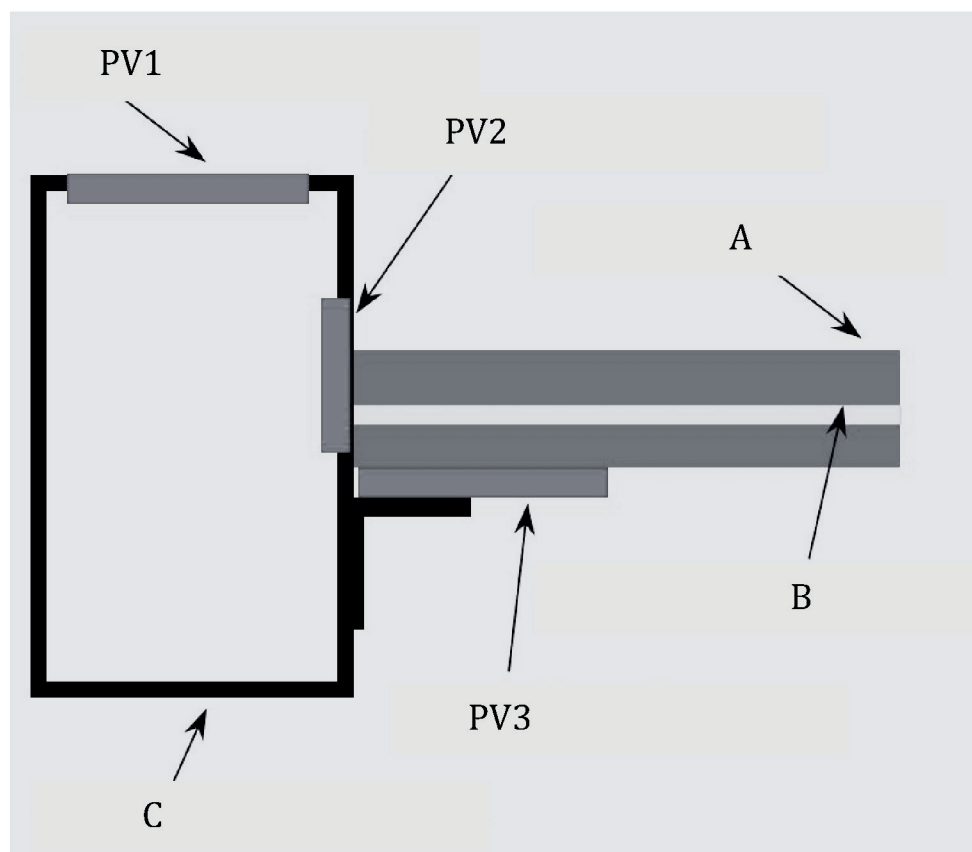
The summations included in [Equation \(10\)](#) are used to account for the various sections of one particular component type; e.g., several values of A_f must be used to sum the contributions of different values of U_{fr} corresponding to sill, head and side jambs.

It should be noted that the two different approaches entail different definitions of frame thermal transmittance, denoted U_f and U_{fr} . The primary difference is that the U_{fr} includes the some of the heat

transfer caused by the edge seal, whereas U_f does not. The comparison of frame properties for two different products is only meaningful if the same calculation procedure has been used in both cases.

The U_t values for windows calculated by the two methods may differ because of differences in the way frame and edge heat transfer is treated at the corners, particularly because the three dimensional effects are neglected. This difference is more pronounced for smaller windows. The choice of $l_{eg} = 63,5$ mm is made to reduce the discrepancy between the two alternative approaches.

4.1.5 Clear Active Window BIPV Schematic



Key

A	laminated glass pane	PV1	front-facing PV modules
B	functionalized interlayer	PV2	PV next to glass edges
C	extruded mounting adaptor	PV3	backside-perimeter PV

Figure 4 — Arrangement of 3 solar PV modules

The schematic arrangement of up to 3 solar PV module subsystem components within clear active window BIPV assembly is shown in [Figure 4](#). The strip-shaped PV modules are placed to surround the internal glass edges and window perimeter areas, using specialised shape of an extruded (metal or plastic) mounting adaptor. Exact mechanical engineering details and details of the overall glazing system may vary dependent on product type, and are normally part of a proprietary design.

Note Clear active window BIPV assemblies are typically not used in door assemblies due to heavy usage.

4.2 Total solar energy transmittance

4.2.1 General

The total solar energy transmittance of the total fenestration product is: where τ_g and τ_f are the individual total solar energy transmittance values of the vision area and frame area, respectively.

$$\tau_s = \frac{\sum \tau_g A_g + \sum \tau_f A_f}{A_t} \quad (13)$$

The summations are included for the same reason that they appear in [Equation \(1\)](#) and shall be applied in the same manner to account for differing sections of one particular component type.

NOTE [Equation \(13\)](#) includes an assumption that the solar transmittance of the edge of glass is the same as that of the centre of glass area.

4.2.2 Vision area total solar energy transmittance

The total solar energy transmittance can be determined for conditions involving internal/external temperature difference and any level of incident solar radiation. It is found by calculating the difference between the net heat flow rate into the internal environment with and without incident solar radiation.

$$\tau_s = \frac{q_{\text{int}} - q_{\text{int}}(I_s = 0)}{I_s} \quad (14)$$

where

- q_{int} is the net density of heat flow rate through the window or door system to the internal environment for the specified conditions, in W/m^2 ;
- $q_{\text{int}}(I_s = 0)$ is the net density of heat flow rate through the window or door system to the internal environment for the specified conditions, but without incident solar radiation, in W/m^2 .

For the equivalent expression for U , see [Equation \(3\)](#).

The net density of heat flow rates, q_{int} and $q_{\text{int}}(I_s = 0)$ are calculated in [5.3.1 \[Equation \(27\)\]](#), for index $i = \text{int}$.

For a glazing assembly in which a shading device is involved, the amendments to the equations of [5.2](#) as given in [7.2](#) shall be applied.

4.2.3 Frame total solar energy transmittance

The frame total solar energy transmittance shall be calculated using the approximate equation:

$$\tau_f = \alpha_f \frac{U_f}{\frac{A_s}{A_f} h_{\text{ex}}} \quad (15)$$

where A_s is the developed surface area.

The external surface heat transfer coefficient (combined convective/radiative) at the frame, h_{ex} , is $h_{\text{ex}} = h_{\text{cv,ex}} + h_{\text{r,ex}}$.

If the alternative method of calculating U_t is being used, U_{fr} should be used instead of U_f in [Equation \(15\)](#).

More detailed two-dimensional or three-dimensional calculations, including the effects of off-normal solar radiation, shading, reflected solar radiation and solar radiation transmitted to the internal frame surfaces, can be performed in a manner analogous to [Equation \(14\)](#), and subject to boundary conditions given in [8.6](#).

4.3 Visible transmittance

The visible transmittance of the total fenestration product is:

$$\tau_t = \frac{\sum \tau_v A_{gv}}{A_t} \quad (16)$$

5 Vision area properties

5.1 Glazing layer optics

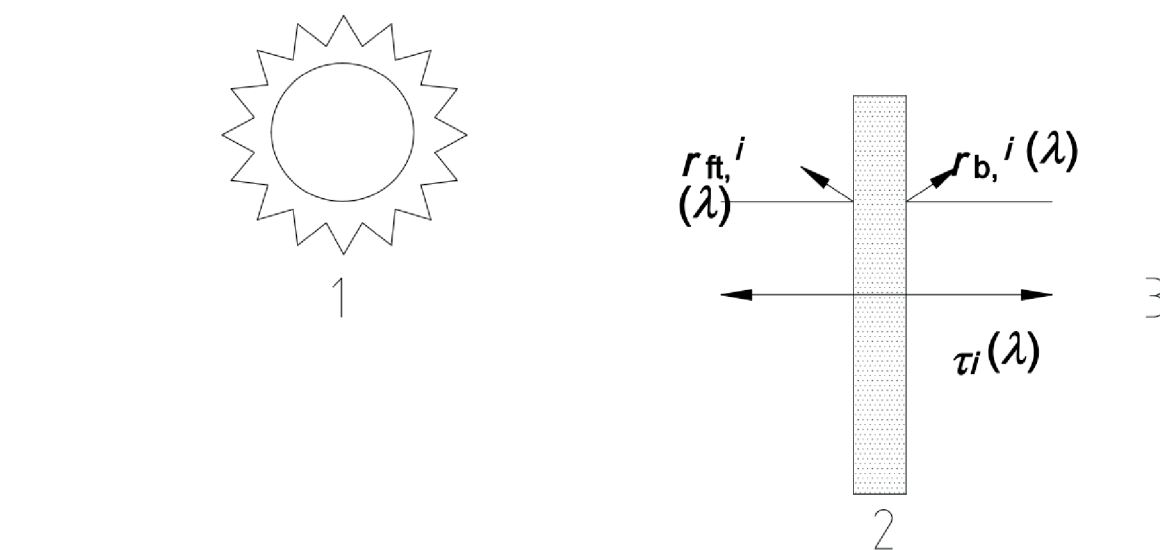
5.1.1 General

For glazing units only, the optical properties can be determined using ISO 9050. [Clause 7](#) contains the extensions needed to model vented windows.

5.1.2 Solar

The solar optical properties needed to describe the i th glazing are: a) the front (external side) spectral reflectance, $r_{ft,i}(\lambda_w)$; b) the back (internal side) spectral reflectance, $r_{b,i}(\lambda_w)$; and c) the spectral transmittance, $\tau_i(\lambda_w)$. See [Figure 5](#).

NOTE More information about $r_{ft,i}(\lambda_w)$, $r_{b,i}(\lambda_w)$ and $\tau_i(\lambda_w)$ can be found in [\[2\]](#).



Key

- 1 outdoor side
- 2 i th glazing layer
- 3 indoor side

Figure 5 — Outdoor and internal spectral transmittance of a glazing layer

The solar optical data shall be measured in accordance with ISO 9050. Intermediate values of $r_{ft,i}(\lambda_w)$, $r_{b,i}(\lambda_w)$ or $\tau_i(\lambda_w)$ are found by linear interpolation.

5.1.3 Long-wave

The long-wave optical properties needed to describe the i th glazing are: a) the front (external side) hemispheric emissivity, $\varepsilon_{\text{ft},i}$; b) the back (internal side) hemispheric emissivity, $\varepsilon_{\text{b},i}$; and c) the hemispheric-hemispheric transmittance, τ_i . These total optical properties apply to wavelengths from 5 μm to 50 μm .

The long-wave reflectance data shall be measured in accordance with EN 12898. Values of the normal emissivity resulting from this procedure shall be converted to hemispherical emissivity using the procedure described in [3] or in EN 12898. The integration needed to convert measured spectral data to the required total longwave optical properties, $\varepsilon_{\text{ft},i}$, $\varepsilon_{\text{b},i}$ and τ_i shall be carried out in accordance with [3] or EN 12898.

Some windows are constructed with suspended or stretched layers of thin plastic film between glass panes to make triple or quadruple glazing. When these layers are covered with a low-emissivity coating they are generally opaque in the infrared, so that $\tau_i = 0$ and hemispherical emissivity can be calculated as in [3]. For partially transparent films such as polyethylene terephthalate (PET), both specular transmittance and reflectance should be measured. Using the bulk model, the optical indices of the material can then be calculated and used to derive the hemispherical properties.

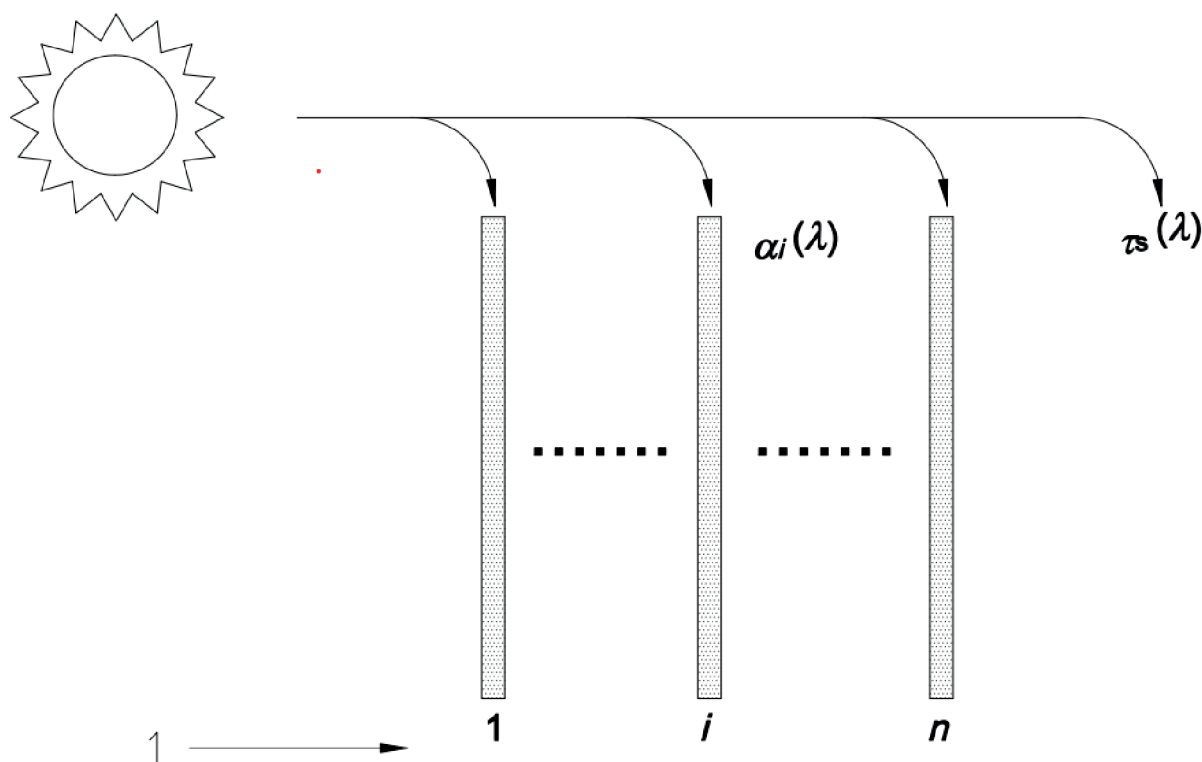
NOTE See [4] for more information.

5.2 Glazing system optics

5.2.1 Spectral quantities

The path of incident solar radiation within the various layers of the glazing system shall be modelled by the methods described in ISO 9050 or by any other exact method.

NOTE Depending on future modifications of ISO 9050, specific additions may be added to this International Standard covering the effects of optical properties of products (shading devices, diffusing panes, etc.) not adequately covered by ISO 9050.



Key

1 glazing layer

Figure 6 — Absorption of the i th glazing layer and solar spectral transmittance

Figure 6 shows how a window with n glazing layers together with the external ($i = 0$) and internal ($i = n + 1$) spaces can be treated as an $n + 2$ element array. It is necessary to determine the portion of incident solar radiation, at a given wavelength, that is absorbed at each of the glazing layers. This quantity is denoted $\alpha_i(\lambda_w)$ at the i th glazing layer. Similarly, it is necessary to determine the solar spectral transmittance of the glazing system, $\tau_s(\lambda_w)$.

These quantities, $\alpha_i(\lambda_w)$ and $\tau_s(\lambda_w)$, shall be calculated in accordance with ISO 9050 while setting the reflectance of the conditioned space to zero. Any other method that can be shown to provide an exact solution is acceptable.

NOTE The solution technique described in [5] is summarized in Annex A.

5.2.2 The solar spectrum

The spectral distribution of the incident solar radiation, $E(\lambda_w)$, is needed to calculate total optical properties and various total energy flow. Values of $E(\lambda_w)$ are reported at N_{sl} values of λ_w (denoted here as $E(\lambda_{wj})$ and λ_{wj} , respectively). Intermediate values of $E(\lambda_w)$ shall be found by linear interpolation of the tabulated values.

5.2.3 Absorbed amounts of solar radiation

The total flow rate of solar radiation absorbed at the i th glazing layer, S_i , is determined by numerical integration over the solar spectrum according to Equations (16), (17) and (18).

$$A_i = \frac{\sum_{j=1}^{N_{sl}-1} \alpha_i(\lambda_{wj/j+1}) E_{sl}(\lambda_{wj/j+1}) \Delta\lambda_{wj}}{\sum_{j=1}^{N_{sl}-1} E_{sl}(\lambda_{wj/j+1}) \Delta\lambda_{wj}} \quad (17)$$

$$\Delta\lambda_{wj} = \lambda_{wj+1} - \lambda_{wj} \quad (18)$$

$$S_i = A_i \times I_{sl} \quad (19)$$

where A_i is the portion of the total incident solar radiation (on the glazing system) that is absorbed by the i th glazing layer, and $\alpha_i(\lambda_{wj/j+1})$ is the value of α_i that is representative of the wavelength band from λ_{wj} to λ_{wj+1} and is given by

$$\alpha_i(\lambda_{wj/j+1}) = \frac{1}{2} \alpha_i(\lambda_{wj}) + \frac{1}{2} \alpha_i(\lambda_{wj+1}) \quad (20)$$

and

$$E_s(\lambda_{wj/j+1}) = \frac{E_s(\lambda_{wj}) + E_s(\lambda_{wj+1})}{2} \quad (21)$$

Values of $E_s(\lambda_w)$ are given in ISO 9845-1.

5.2.4 Solar transmittance

The solar transmittance of the glazing system is:

$$\tau_{sl} = \frac{\sum_{j=1}^{N_{sl}-1} \tau_{sl}(\lambda_{wj/j+1}) E_s(\lambda_{wj/j+1}) \Delta\lambda_{wj}}{\sum_{j=1}^{N_{sl}-1} E_s(\lambda_{wj/j+1}) \Delta\lambda_{wj}} \quad \Delta\lambda_{wj} = \lambda_{wj+1} - \lambda_{wj} \quad (22)$$

where $E_s(\lambda_{wj/j+1})$ is given by [Equation \(21\)](#) and

$$\tau_{sl}(\lambda_{wj/j+1}) = \frac{1}{2} \tau_{sl}(\lambda_{wj}) + \frac{1}{2} \tau_{sl}(\lambda_{wj+1}) \quad (23)$$

5.2.5 Visible transmittance

Visible transmittance, τ_{vs} , is calculated using a weighting function that represents the photopic response of the eye, $R(\lambda_w)$. $R(\lambda_w)$ is tabulated for N_{vs} values of λ_{wj} . τ_{vs} is given by:

$$\tau_{vs} = \frac{\sum_{j=1}^{N_{vs}-1} \tau_{sl}(\lambda_{wj/j+1}) E_{vs}(\lambda_{wj/j+1}) R(\lambda_{wj/j+1}) \Delta\lambda_{wj}}{\sum_{j=1}^{N_{vs}-1} E_{vs}(\lambda_{wj/j+1}) R(\lambda_{wj/j+1}) \Delta\lambda_{wj}} \quad \Delta\lambda_{wj} = \lambda_{wj+1} - \lambda_{wj} \quad (24)$$

where

$$R(\lambda_{wj/j+1}) = \frac{R(\lambda_{wj}) + R(\lambda_{wj+1})}{2} \quad (25)$$

$$E_{vs}(\lambda_{wj/j+1}) = \frac{1}{2} E_{vs}(\lambda_{wj}) + \frac{1}{2} E_{vs}(\lambda_{wj+1}) \quad (26)$$

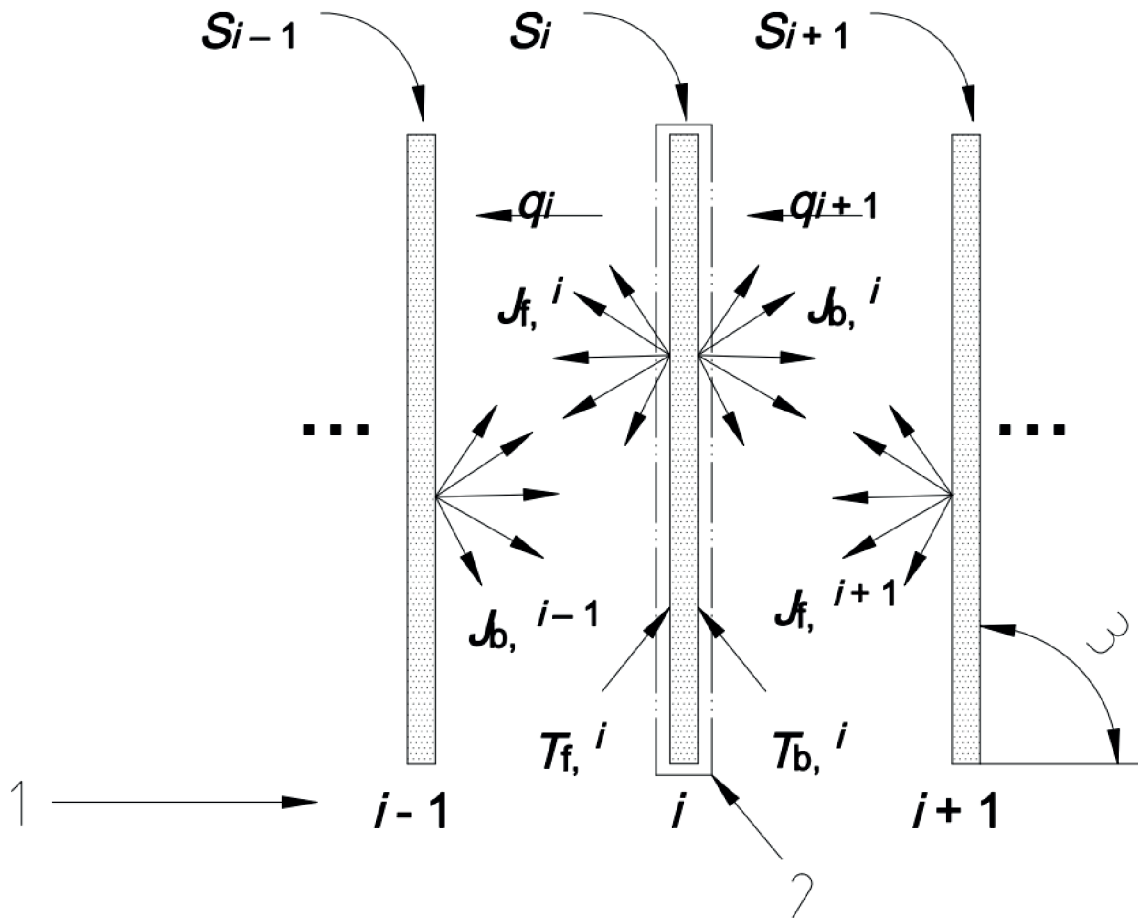
Values of $E_v(\lambda_w)$ are given in ISO/CIE 10526.

and $\tau_{sl}(\lambda_{wj/j+1})$ is given by [Equation \(23\)](#).

5.3 Vision area heat transfer

5.3.1 Glazing layer energy balance

Longwave radiative exchange between glazing layers and conductive heat transfer within each glazing layer can be described using fundamental relations. Calculations dealing with convective heat transfer depend upon correlations based on experimental data.



Key

- 1 glazing layer
- 2 control volume
- 3 slope

Figure 7 — Energy balance on glazing layer i

Figure 7 shows the i th glazing in a sloped multilayer array. The values of four variables are sought at each glazing. These are the temperatures of the external and internal facing surfaces, $T_{f,i}$ and $T_{b,i}$ plus the radiant heat leaving the front and back facing surfaces (i.e., the radiosities), $J_{f,i}$ and $J_{b,i}$. In terms of these variables, q_i is:

$$q_i = h_{cv,i} (T_{f,i} - T_{b,i-1}) + J_{f,i} - J_{b,i-1} \quad (27)$$

The solution is generated by applying the following four equations at each glazing:

$$q_i = S_i + q_{i+1} \quad (28)$$

$$J_{f,i} = \varepsilon_{f,i} \sigma T_{f,i}^4 + \tau_i J_{f,i+1} + r_{f,i} J_{b,i-1} \quad (29)$$

$$J_{b,i} = \varepsilon_{b,i} \sigma T_{b,i}^4 + \tau_i J_{b,i-1} + r_{b,i} J_{f,i+1} \quad (30)$$

$$T_{b,i} - T_{ft,i} = \frac{t_{gv,i}}{2\lambda_{gv,i}} (2q_{i+1} + S_i) \quad (31)$$

A by-product of the analysis is the temperature profile through each glazing.

$$T_i(z) = \left(\frac{-S_i}{2\lambda_{gv,i}t_{gv,i}} \right) z^2 + \left(\frac{T_{ft,i} - T_{b,i}}{t_{gv,i}} + \frac{S_i}{2\lambda_{gv,i}} \right) z + T_{b,i} \quad (32)$$

where z is the distance from the internal surface of the glazing, positive in the direction of the external side.

[Equation \(28\)](#) describes an energy balance imposed at the surfaces of the i th glazing. [Equations \(29\)](#) and [\(30\)](#) define the radiosities at the glazing, and $r_{ft,i} = 1 - \tau_i - \varepsilon_{ft,i}$ and $r_{b,i} = 1 - \tau_i - \varepsilon_{b,i}$.

The temperature difference across the i th glazing is given by [Equation \(31\)](#). It is assumed that the solar energy is absorbed uniformly through the thickness of the glazing.

NOTE More details regarding [Equation \(27\)](#) to [Equation \(32\)](#) are given in References [5] and [35].

5.3.2 Interaction with the environment

The effect of boundary conditions imposed by the environment on the window shall be specified. The internal and external temperatures, $T_{ft,n+1}$ and $T_{b,0}$ are:

$$T_{ft,n+1} = T_{ai,int} \quad (33)$$

$$T_{b,0} = T_{ai,ex} \quad (34)$$

The effect of long-wave irradiance at internal and external glazing surfaces is included by setting

$$J_{ft,n+1} = E_{gv,int} \quad (35)$$

$$\text{and } J_{b,0} = E_{gv,ex} \quad (36)$$

where $E_{gv,int}$ and $E_{gv,ex}$ are given by [Equations \(159\)](#) and [\(152\)](#) in [Clause 8](#), respectively.

The effect of the convective heat transfer coefficients at the glazing surfaces is included by setting

$$h_{cv,n+1} = h_{cv,int} \quad (37)$$

$$h_{cv,1} = h_{cv,ex} \quad (38)$$

5.3.3 Convective heat transfer coefficient — glazing cavities

5.3.3.1 General

Convective heat transfer coefficients for the fill gas layers are determined in terms of the dimensionless Nusselt number, Nu_i :

$$h_{cv,i} = Nu_i \left(\frac{\lambda_{gv,i}}{d_{gv,i}} \right) \quad (39)$$

where $d_{gv,i}$ is the thickness of the fill gas layer (or pane spacing) i , and $\lambda_{gv,i}$ is the thermal conductivity of the fill gas. Nu_i is calculated using correlations based on experimental measurements of heat transfer across inclined air layers. Nu_i is a function of the Rayleigh number, Ra_i , the cavity aspect ratio, $A_{gv,i}$, and the cavity slope, γ .

It should be recognized that deflection of the panes in high aspect ratio cavities can occur. This deflection may increase or decrease the average cavity width, d . This deflection can be caused by changes in the cavity average temperature, changes in the cavity moisture content, nitrogen absorption by the desiccant or changes in the barometric pressure (due to elevation and/or weather changes) from the conditions during assembly.

NOTE Reference [6] discusses the effects of glass pane deflection and methods to estimate the change in the thermal transmittance due to this deflection.

The Rayleigh number can be expressed as (omitting the “ i ” and “ gv ” subscripts for convenience):

$$Ra = \frac{\rho^2 d^3 g \beta c_p \Delta T}{\mu \lambda} \text{ (dimensionless)} \quad (40)$$

Treating the fill gas as a perfect gas, the thermal expansion coefficient of the fill gas, β , is:

$$\beta = \frac{1}{T_m} \quad (41)$$

where T_m = fill gas mean temperature in kelvins.

The aspect ratio of the fill gas cavity i , is:

$$A_{gv,i} = \frac{H}{d_{gv,i}} \quad (42)$$

where H is the distance between the top and bottom of the fill gas cavity which is usually the same as the height of the window view area.

Correlation to quantify convective heat transfer across glazing cavities is presented in the 5.3.3.2 to 5.3.3.6. Each of these subclauses pertains to one particular value, or range, of tilt angle, γ .

This categorization, as a function of γ , is based on the assumption that the cavity is heated from the internal side (i.e., $T_{ft,i} > T_{b,i-1}$). If the reverse is true ($T_{ft,i} < T_{b,i-1}$) it is necessary to seek the appropriate correlation on the basis of the complement of the tilt angle, $180^\circ - \gamma$, instead of γ and to then substitute $180^\circ - \gamma$ instead of γ when the calculation is carried out.

$\gamma = 0$ is horizontal glazing, heat flow upwards

$\gamma = 90$ is vertical glazing, heat flow upwards

$\gamma = 180$ is horizontal glazing, heat flow downwards

5.3.3.2 Cavities inclined at $0 < \gamma < 60^\circ$

$$Nu_i = 1 + 1,44 \left(1 - \frac{1708}{Ra \cos(\gamma)} \right)^{\bullet} \left[1 - \frac{(1708 \sin^{1,6}(1,8\gamma))}{Ra \cos(\gamma)} \right] + \left[\left(\frac{Ra \cos(\gamma)}{5830} \right)^{1/3} - 1 \right]^{\bullet} \quad (43)$$

$$Ra < 10^5 \text{ and } A_{gv,i} > 20$$

$$\text{where } (X)^{\bullet} = \frac{(X + |X|)}{2} \quad (44)$$

NOTE For more details, see Reference [7].

5.3.3.3 Cavities inclined at $\gamma = 60^\circ$

$$Nu = (Nu_1, Nu_2)_{\max} \quad (45)$$

$$\text{where } Nu_1 = \left[1 + \left(\frac{0,0936 Ra^{0,314}}{1+G} \right)^7 \right]^{1/7} \quad (46)$$

$$Nu_2 = \left(0,104 + \frac{0,175}{A_{g,i}} \right) Ra^{0,283} \quad (47)$$

$$G = \frac{0,5}{\left[1 + \left(\frac{Ra}{3160} \right)^{20,6} \right]^{0,1}} \quad (48)$$

NOTE For more details, see Reference [8].

5.3.3.4 Cavities inclined at $60^\circ < \gamma < 90^\circ$

For layers inclined at angles between 60° and 90° , a straight-line interpolation between the results of [Equations \(45\)](#) and [\(49\)](#) is used. These equations are valid in the ranges of:

$$10^2 < Ra < 2 \times 10^7 \text{ and } 5 < A_{gv,i} < 100$$

NOTE For more details, see Reference [8].

5.3.3.5 Vertical cavities

$$Nu = (Nu_1, Nu_2)_{\max} \quad (49)$$

$$Nu_1 = 0,0673838 Ra^{1/3} \quad 5 \times 10^4 < Ra \quad (50)$$

$$Nu_1 = 0,028154 Ra^{0,4134} \quad 10^4 < Ra \leq 5 \times 10^4 \quad (51)$$

$$Nu_1 = 1 + 1,7596678 \times 10^{-10} Ra^{2,2984755} \quad Ra \leq 10^4 \quad (52)$$

$$Nu_2 = 0,242 \left(\frac{Ra}{A_{gv,i}} \right)^{0,272} \quad (53)$$

NOTE For more details, see Reference [9].

5.3.3.6 Cavities inclined from 90° to 180°

Gas layers contained in downward facing windows are modelled using:

$$Nu = 1 + (Nu_v - 1) \sin \gamma \quad (54)$$

Nu_v is the Nusselt number for a vertical cavity given by [Equation \(49\)](#).

NOTE For more details, see Reference [10].