# INTERNATIONAL STANDARD

# ISO 15099

First edition
2003-11-15

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

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



Reference number
ISO 15099:2003(E)

# Contents

# Foreword

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

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

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

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

ISO 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 window 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 $\tau_S$-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.

## 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 hot box method — Part 1: Complete windows and doors*

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

# 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 |
| $A_\mathrm{R}$ | 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 |
| $d_\mathrm{g}$ | thickness of glazing cavity | m |
| $E$ | irradiance | W/m$^2$ |
| $E_\mathrm{s}(\lambda)$ | solar spectral irradiance function (see ISO 9845-1) | 1 |
| $E_\mathrm{v}(\lambda)$ | 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$^2$ |
| $I_i^+(\lambda)$<br>$I_i^-(\lambda)$ | 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 |

**Table 1** (*continued*)

| Symbol | Term | Unit |
|---|---|---|
| $J$ | radiosity | W/m$^2$ |
| $l$ | length | m |
| $\hat{M}$ | 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 laver | W/m$^2$ |
| $t_{\text{perp}}$ | largest dimension of frame cavity perpendicular to heat flow | m |
| $T$ | thermodynamic temperature | K |
| $\Delta T_i$ | temperature drop across $i$th glazing cavity, $\Delta T_i = \lvert T_{\text{f},i} - T_{\text{b},i+1} \rvert$ | 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 |
| $\alpha$ | absorption | 1 |
| $\beta$ | thermal expansion coefficient of fill gas | K$^{-1}$ |
| $\varepsilon$ | total hemispherical emissivity | 1 |
| $\gamma$ | angle | ° |
| $\theta$ | temperature | °C |
| $\sigma$ | Stefan-Boltzmann constant, 5,669 3 × 10$^{-8}$ | W/(m$^2$·K$^4$) |
| $\lambda$ | thermal conductivity | W/(m·K) |
| $\lambda_{\text{w}}$ | wavelength | m |
| $\mu$ | dynamic viscosity | Pa·s |
| $\rho$ | density | kg/m$^3$ |
| $\tau$ | transmittance | 1 |
| $\tau_{\text{S}}$ | 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 |
| $\phi$ | parameter used in the calculation of viscosity and of thermal conductivity; see Equations (62) and (67) | 1 |
| $\varphi$ | function used in the calculation of heat transfer; see Equation (112) | 1 |
| $\Phi$ | heat flow rate | W |
| $\Psi$ | 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 |
| $n$ | counter |
| ne | environmental (external) |
| ni | environmental (internal) |
| out | outlet of a gap |
| p | panel |
| r | radiation or radiant |
| red | reduced radiation |
| s | surface |
| sc | source |
| sk | sink |
| sl | solar |
| t | total |
| tp | top of a gap |
| $\nu$ | number of gases in a gas mixture |
| v | vertical |
| $z$ | at distance $z$ |
| $\Psi$ | perimeter |
| $2D$ | coupling |

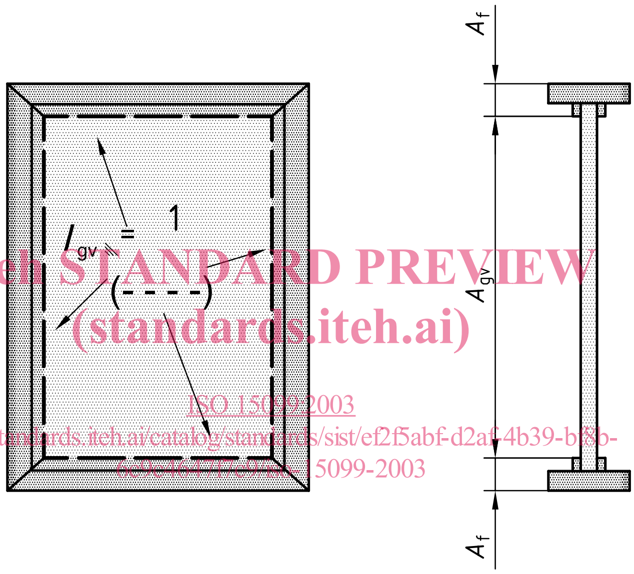
# 4 Determination of total window and door system properties

## 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**

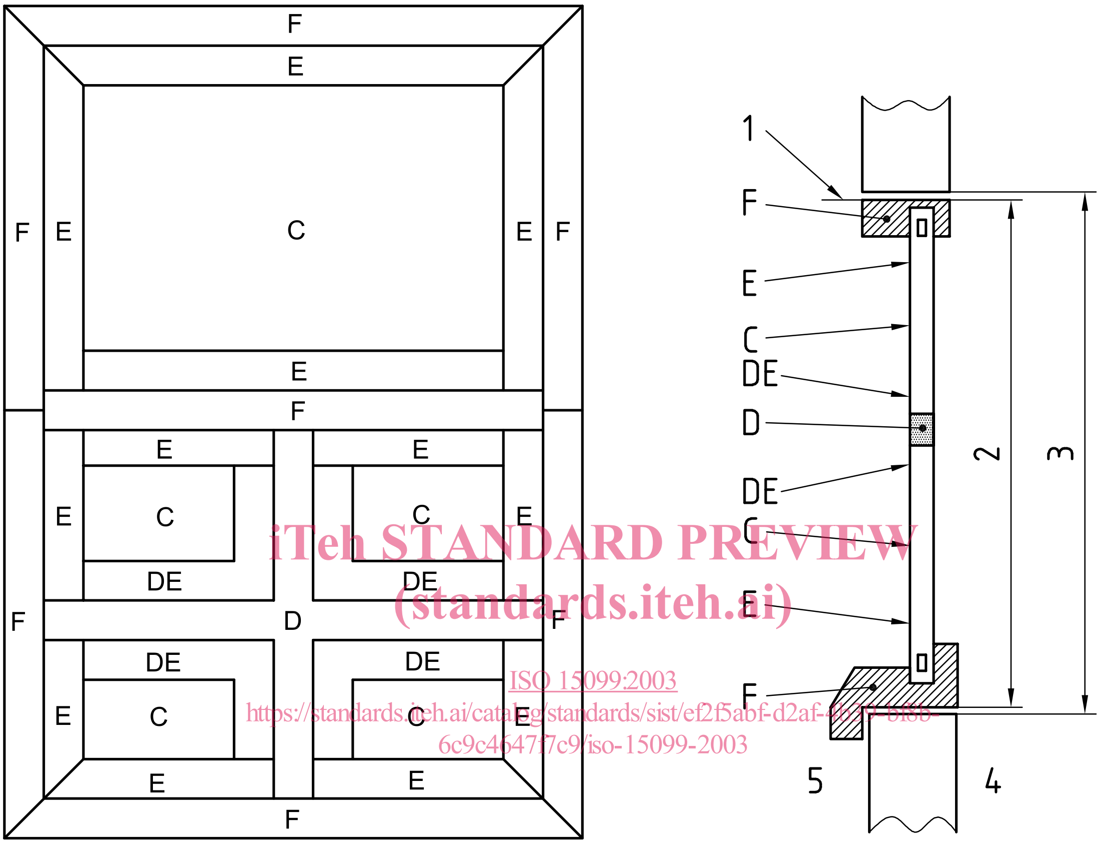
Clause 4 describes the procedure for calculating thermal transmittance, total solar transmittance and visible transmittance for the complete product. 4.1 describes the procedure for calculating thermal transmittance. The effect of three-dimensional heat transfer in frames and glazing units is not considered. 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 $\tau_{sgv}$ and $\tau_{gv}$. Clause 6 describes the procedure for calculating the linear thermal transmittance, $\Psi$, 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 $l_\Psi$, and $\Psi$ 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.

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

and when solar radiation is considered, then:

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

where $q_{int}(I_s = 0)$ 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/m². 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 $\tau_S$-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):

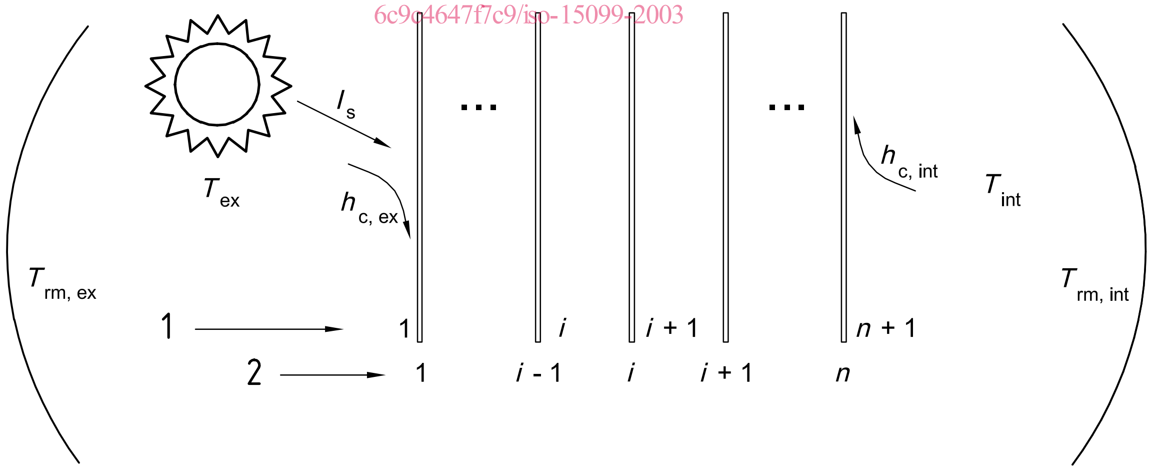
$$R_i = \frac{T_{f,i} - T_{b,i-1}}{q_i} \quad (6)$$

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, $\Psi$, values and frame thermal transmittances shall be calculated according to the following equations.

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

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

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

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, $\Psi$. 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:

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

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

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

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

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 $\Phi_{fr}$ and $\Phi_{eg}$ 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.

## 4.2 Total solar energy transmittance

### 4.2.1 General

The total solar energy transmittance of the total fenestration product is:

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

where $\tau_g$ and $\tau_f$ are the individual total solar energy transmittance values of the vision area and frame area, respectively. 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.

$$\tau_S = \frac{q_{int} - q_{int}\left(I_s = 0\right)}{I_s} \qquad (14)$$

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$^2$;

$q_{int}(I_s = 0)$ 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 $q_{int}(I_s = 0)$ are calculated in 5.3.1 [Equation (27), for index $i$ = 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.