INTERNATIONAL STANDARD

ISO
10077-1

Second edition
2006-09-15

Thermal performance of windows, doors and shutters — Calculation of thermal transmittance —

Part 1:
General

Performance thermique des fenêtres, portes et fermetures — Calcul du coefficient de transmission thermique —

Partie 1: Généralités

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Foreword

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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 10077-1 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This second edition cancels and replaces the first edition (ISO 10077-1:2000), the following clauses and subclauses of which have been technically revised.

Clause	Changes
Introduction	Added new paragraph explaining the various parts of the overall thermal transmittance
1	Amended 4th paragraph to permit calculation of U-value of roof windows
2	References to ISO rather than EN ISO where applicable
4.3	Added "including sashes if present" to the definition of areas
4.4	Clarification that sealing gaskets are ignored in the determination of areas. Dimensions to be measured to nearest mm.
5.1.1	Third from last paragraph inserted concerning roof windows
5.3	Data on shutters moved to Annex G
6	Added paragraph to say that declared values are to be obtained for horizontal heat flow (as in ISO 10292 and EN 673)
7.1	Second dash, drawing to give details also for metal frames
Table A.1	Added surface resistance values for horizontal or inclined window
Annex E	Complete revision of Annex E. It has been changed to normative, because it provides default values that are to be used in the absence of detailed values.
Annex F	Complete revision of Annex F, using the new values in Annex E

ISO 10077 consists of the following parts, under the general title *Thermal performance of windows, doors and shutters — Calculation of thermal transmittance*:

⎯ *Part 1: General*

⎯ *Part 2: Numerical method for frames*

Introduction

The calculation method described in this part of ISO 10077 is used to evaluate the thermal transmittance of windows and doors, or as part of the determination of the energy use of a building.

An alternative to calculation is testing of the complete window or door according to ISO 12567-1 or, for roof windows, according to ISO 12567-2.

The calculation is based on four component parts of the overall thermal transmittance:

— for elements containing glazing, the thermal transmittance of the glazing, calculated using EN 673 or measured according to EN 674 or EN 675;

— for elements containing opaque panels, the thermal transmittance of the opaque panels, calculated according to ISO 6946 and/or ISO 10211 (all parts) or measured according to ISO 8301 or ISO 8202;

— thermal transmittance of the frame, calculated using ISO 10077-2, measured according to EN 12412-2, or taken from Annex D of this part of ISO 10077;

— linear thermal transmittance of the frame/glazing junction, calculated according to ISO 10077-2 or taken from Annex E of this part of ISO 10077.

More detailed equations for calculation of heat flow through windows can be found in ISO 15099.

The thermal transmittance of curtain walling can be calculated using prEN 13947.

EN 13241-1 gives procedures applicable to doors intended to provide access for goods and vehicles.

Thermal performance of windows, doors and shutters — Calculation of thermal transmittance —

Part 1:
General

1   Scope

This part of ISO 10077 specifies methods for the calculation of the thermal transmittance of windows and pedestrian doors consisting of glazed and/or or opaque panels fitted in a frame, with and without shutters.

This part of ISO 10077 allows for

— different types of glazing (glass or plastic; single or multiple glazing; with or without low emissivity coatings, and with spaces filled with air or other gases);

— opaque panels within the window or door;

— various types of frames (wood, plastic, metallic with and without thermal barrier, metallic with pinpoint metallic connections or any combination of materials);

— where appropriate, the additional thermal resistance introduced by different types of closed shutter, depending on their air permeability.

The thermal transmittance of roof windows and other projecting windows can be calculated according to this part of ISO 10077, provided that the thermal transmittance of their frame sections is determined by measurement or by numerical calculation.

Default values for glazing, frames and shutters are given in the informative annexes. Thermal bridge effects at the rebate or joint between the window or door frame and the rest of the building envelope are excluded from the calculation.

The calculation does not include

— effects of solar radiation,

— heat transfer caused by air leakage,

— calculation of condensation,

— ventilation of air spaces in double and coupled windows,

— surrounding parts of an oriel window.

The part of ISO 10077 does not apply to

— curtain walls and other structural glazing,

— industrial, commercial and garage doors.

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 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

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

ISO 10211 (all parts), *Thermal bridges in building construction — Heat flows and surface temperatures — Detailed calculations*

ISO 12567-2, *Thermal performance of windows and doors — Determination of thermal transmittance by hot box method — Part 2: Roof windows and other projecting windows*

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 12412-2, *Thermal performance of windows, doors and shutters — Determination of thermal transmittance by hot box method — Part 2: Frames*

3   Terms, definitions, symbols and units

3.1   Terms and definitions

For the purposes of this document, the terms and definitions given in EN 673 and ISO 7345 apply.

In Clause 4 of this part of ISO 10077, descriptions are given of a number of geometrical characteristics of glazing and frame.

3.2 Symbols and units

Symbol	Quantity	Unit
A	area	m^2
R	thermal resistance	$m^2 \cdot K/W$
U	thermal transmittance	$W/(m^2 \cdot K)$
b	width	m
d	distance, thickness	m
l	length	m
q	density of heat flow rate	W/m^2
Ψ	linear thermal transmittance	$W/(m \cdot K)$
λ	thermal conductivity	$W/(m \cdot K)$

3.3 Subscripts

D	door	i	internal
W	window	j	summation index
WS	window with closed shutter	p	panel (opaque)
d	developed	s	space (air or gas space)
e	external	se	external surface
f	frame	sh	shutter
g	glazing	si	internal surface

4 Geometrical characteristics

4.1 Glazed area, opaque panel area

The glazed area, A_g, or the opaque panel area, A_p, of a window or door is the smaller of the visible areas seen from both sides; see Figure 1. Any overlapping of gaskets is ignored.

4.2 Total visible perimeter of the glazing

The total perimeter of the glazing, l_g, (or the opaque panel, l_p) is the sum of the visible perimeter of the glass panes (or opaque panels) in the window or door. If the perimeters are different on either side of the pane or panel, then the larger of the two shall be used; see Figure 1.
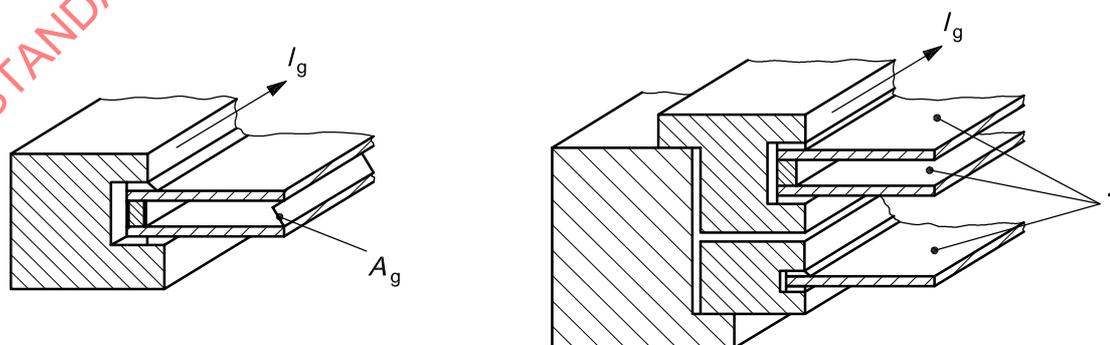
Key

1 glass

Figure 1 — Illustration of glazed area and perimeter

4.3 Frame areas

For the definition of the areas, see also Figure 3.

$A_{f,i}$ Internal projected frame area:

     The internal projected frame area is the area of the projection of the internal frame, including sashes if present, on a plane parallel to the glazing panel.

$A_{f,e}$ External projected frame area:

     The external projected frame area is the area of the projection of the external frame, including sashes if present, on a plane parallel to the glazing panel.
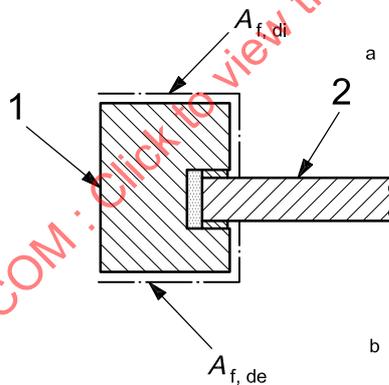
A_f Frame area:

     The frame area is the larger of the two projected areas seen from both sides.

$A_{f,di}$ Internal developed frame area:

     The internal developed frame area is the area of the frame, including sashes if present, in contact with the internal air (see Figure 2).

$A_{f,de}$ External developed frame area:

     The external developed frame area is the area of the frame, including sashes if present, in contact with the external air (see Figure 2).

Key

1   frame
2   glazing

a   Internal.
b   External.

Figure 2 — Internal and external developed area

4.4 Window area

The window area, A_w, is the sum of the frame area, A_f, and the glazing area, A_g, (or the panel area, A_p).

The frame area and the glazed area are defined by the edge of the frame, i.e. sealing gaskets are ignored for the purposes of determination of the areas.

Window dimensions (height, width, frame width and frame thickness) shall be determined to the nearest millimetre.
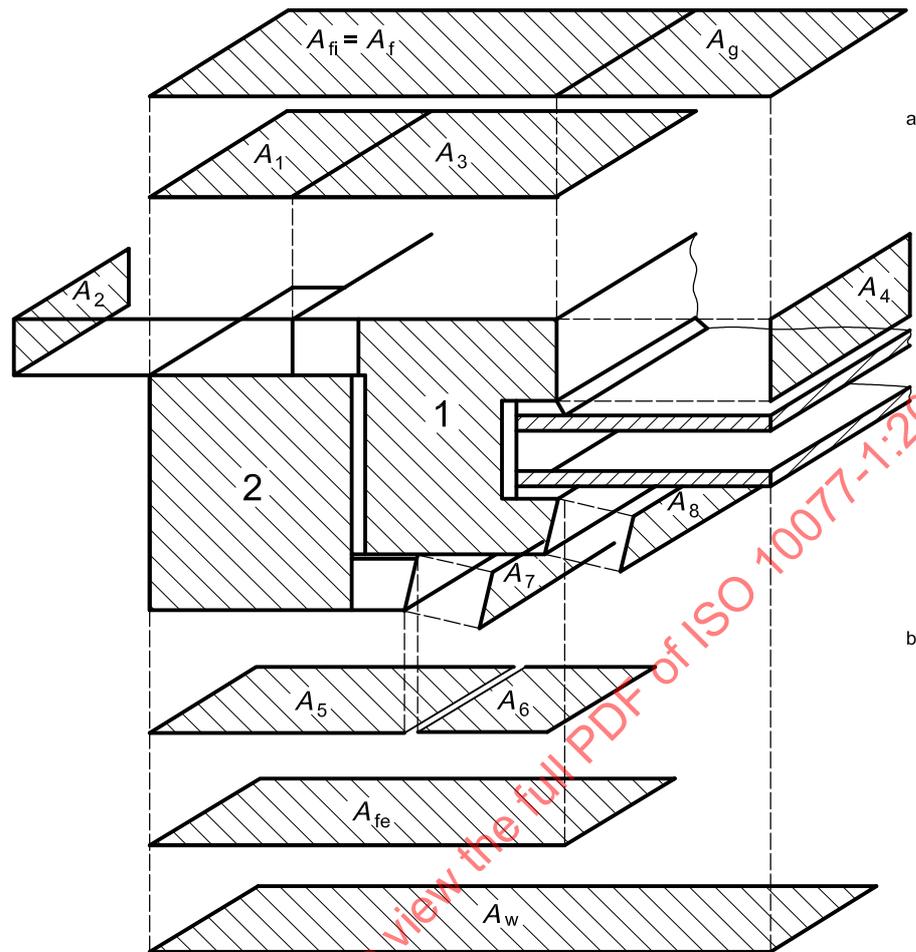
Key

1 sash (moveable)
2 frame (fixed)

a Internal.
b External.

$A_\text{f} = \max{(A_\text{f,i}; A_\text{f,e})}$
$A_\text{w} = A_\text{f} + A_\text{g}$
$A_\text{f,di} = A_1 + A_2 + A_3 + A_4$
$A_\text{f,de} = A_5 + A_6 + A_7 + A_8$

NOTE 1 The frame area, A_f, includes the area of the fixed frame together with that of any moveable sash or casement.

NOTE 2 Drip trays and similar protuberances are not considered as parts of the developed area.

Figure 3 — Illustration of the various areas

5

5 Calculation of thermal transmittance

5.1 Windows

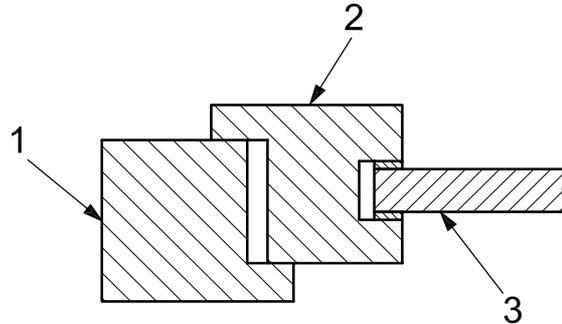#### 5.1.1 Single windows

Key

1 frame (fixed)
2 sash (moveable)
3 glazing (single or multiple)

Figure 4 — Illustration of single window

The thermal transmittance of a single window, U_W, shall be calculated using Equation (1):

$$U_W = \frac{\sum A_g U_g + \sum A_f U_f + \sum l_g \Psi_g}{\sum A_g + \sum A_f} \tag{1}$$

where

U_g is the thermal transmittance of the glazing;

U_f is the thermal transmittance of the frame;

Ψ_g is the linear thermal transmittance due to the combined thermal effects of glazing, spacer and frame;

and the other symbols are defined in Clause 4. The summations included in Equation (1) are used to allow for different parts of the glazing or frame, e.g. several values of A_f are needed when different values of U_f apply to the sill, head, jambs and dividers.

In the case of single glazing the last term of the numerator in Equation (1) shall be taken as zero (no spacer effect) because any correction is negligible.

When there are both opaque panels and glazed panes, U_W, is calculated using Equation (2):

$$U_W = \frac{\sum A_g U_g + \sum A_p U_p + \sum A_f U_f + \sum l_g \Psi_g + \sum l_p \Psi_p}{\sum A_g + \sum A_p + \sum A_f} \tag{2}$$

where

U_p is the thermal transmittance of the opaque panel(s);

Ψ_p is the linear thermal transmittance for the opaque panel(s).

Ψ_p may be taken as zero if

— the internal and external facings of the panel are of material with thermal conductivity less than 0,5 W/(m·K), and

— the thermal conductivity of any bridging material at the edges of the panel is less than 0,5 W/(m·K).

In other cases, Ψ_p shall be calculated in accordance with ISO 10077-2.

U_g shall be obtained in accordance with 5.2.

U_f for roof windows shall be either

— calculated in accordance with ISO 10077-2, or

— measured in accordance with EN 12412-2 with specimens mounted within the aperture in the surround panel flush with the cold side, in accordance with in ISO 12567-2.

For other windows, U_f shall be

— calculated in accordance with ISO 10077-2, or

— measured in accordance with EN 12412-2, or

— obtained from Annex D.

Linear thermal transmittance may be calculated in accordance with ISO 10077-2 or taken from Annex E.

5.1.2 Double windows

Dimensions in millimetres

Key
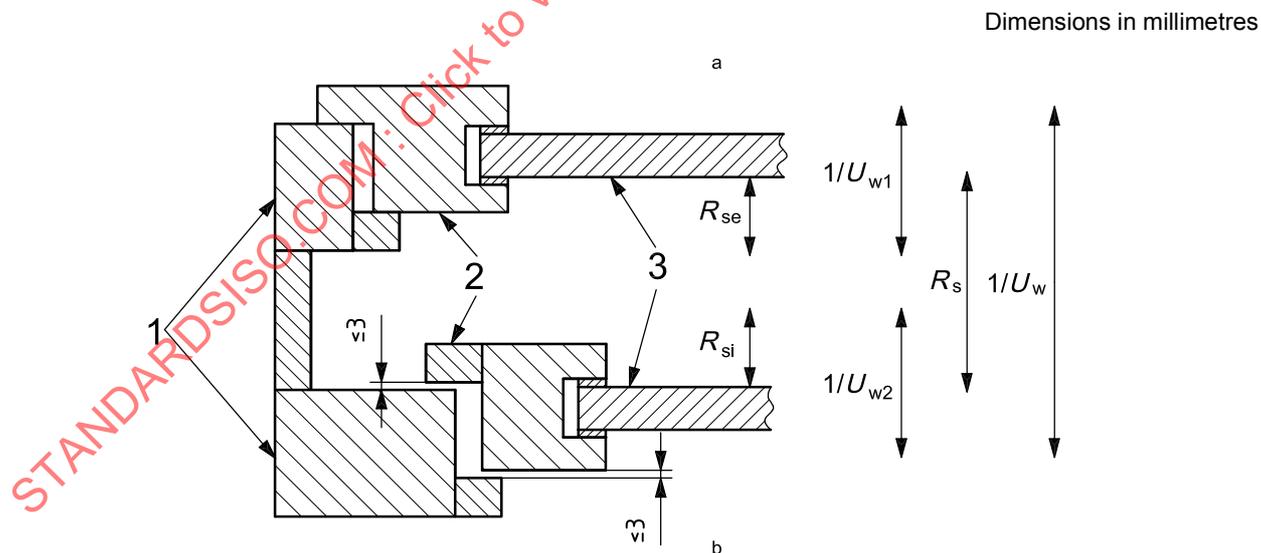
1   frame (fixed)
2   sash (moveable)
3   glazing (single or multiple)

[a]   Internal.
[b]   External.

Figure 5 — Illustration of double window

The thermal transmittance, U_W, of a system consisting of two separate windows shall be calculated using Equation (3).

$$U_W = \frac{1}{1/U_{W1} - R_{si} + R_s - R_{se} + 1/U_{W2}}$$ (3)

where

U_{W1}, U_{W2} are the thermal transmittances of the external and internal window, respectively, calculated according to Equation (1);

R_{si} is the internal surface resistance of the external window when used alone;

R_{se} is the external surface resistance of the internal window when used alone;

R_s is the thermal resistance of the space between the glazing in the two windows.

NOTE   Typical values of R_{si} and R_{se} are given in Annex A and of R_s, in Annex C.

If either of the gaps shown in Figure 5 exceeds 3 mm and measures have not been taken to prevent excessive air exchange with external air, the method does not apply.

5.1.3 Coupled windows

Dimensions in millimetres
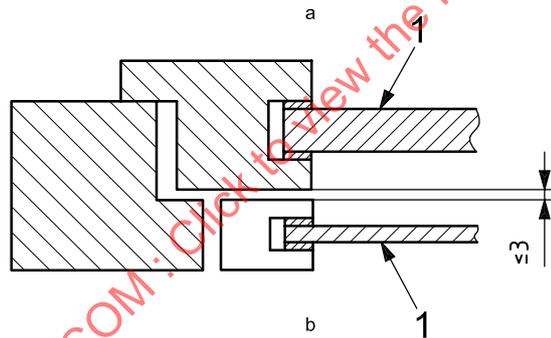
Key

1   glazing (single or multiple)

a   Internal.

b   External.

Figure 6 — Illustration of coupled windows

The thermal transmittance, U_W, of a system consisting of one frame and two separate sashes or casements shall be calculated using Equation (1). To determine the thermal transmittance, U_g, of the combined glazing Equation (4) shall be used:

$$U_g = \frac{1}{1/U_{g1} - R_{si} + R_s - R_{se} + 1/U_{g2}}$$ (4)

where

U_{g1}, U_{g2} are the thermal transmittances of the external and internal glazing; respectively, calculated in accordance with Equations (5) and (6);

R_{si} is the internal surface resistance of the external glazing when used alone;

R_{se} is the external surface resistance of the internal glazing when used alone;

R_s is the thermal resistance of the space between the internal and external glazing.

NOTE   Typical values of R_{si} and R_{se} are given in Annex A and of R_s, in Annex C.

If the gap exceeds 3 mm and measures have not been taken to prevent excessive air exchange with external air, the method does not apply.

5.2 Glazing

5.2.1 Single glazing

The thermal transmittance of the single and laminated glazing, U_g, shall be calculated using Equation (5).

$$U_g = \frac{1}{R_{se} + \sum_j \dfrac{d_j}{\lambda_j} + R_{si}}$$
(5)

where

R_{se} is the external surface resistance;

λ_j is the thermal conductivity of glass or material layer j;

d_j is the thickness of the glass pane or material layer j;

R_{si} is the internal surface resistance.

NOTE   Typical values of R_{se} and R_{si} are given in Annex A.

5.2.2 Multiple glazing

The thermal transmittance of multiple glazing, U_g, can be calculated in accordance with EN 673 or by means of Equation (6):

$$U_g = \frac{1}{R_{se} + \sum_j \dfrac{d_j}{\lambda_j} + \sum_j R_{s,j} + R_{si}}$$
(6)

where

R_{se} is the external surface resistance;

λ_j is the thermal conductivity of glass or material layer j;

d_j is the thickness of the glass pane or material layers j;

R_{si} is the internal surface resistance;

$R_{s,j}$ is the thermal resistance of air space j.

NOTE   Typical values of R_s are given in Annex C.

5.3 Windows with closed shutters

A shutter on the outside of a window introduces an additional thermal resistance, resulting from both the air layer enclosed between the shutter and the window, and the shutter itself (see Figure 7). The thermal transmittance of a window with closed shutters, U_{WS}, is given by Equation (7):

$$U_{WS} = \frac{1}{1/U_W + \Delta R} \tag{7}$$

where

U_W is the thermal transmittance of the window;

ΔR is the additional thermal resistance due to the air layer enclosed between the shutter and the window and the closed shutter itself (see Figure 7).
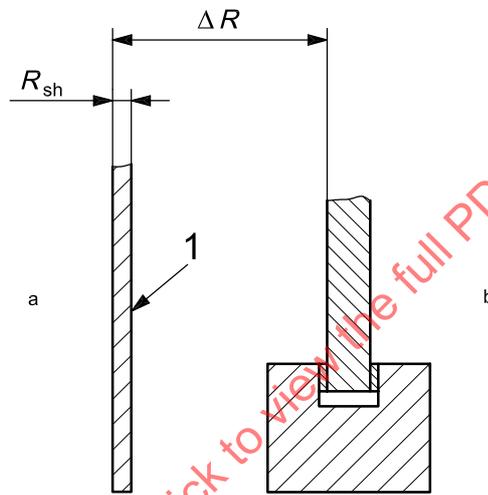
Key

1 shutter

a Internal.

b External.

Figure 7 — Window with external shutter

ΔR depends on the thermal transmission properties of the shutter and on its air permeability. Further information is given in Annex G.

5.4 Doors

5.4.1 Fully glazed doors

Key
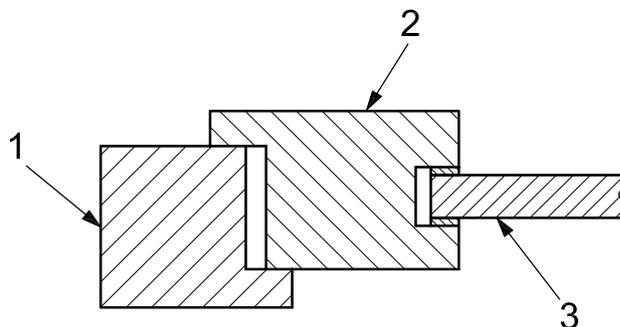
1   frame (fixed)
2   sash (moveable)
3   glazing (single or multiple)

Figure 8 — Illustration of door with glazing

The thermal transmittance, U_D, of a door set of which the door leaf is fully glazed is obtained using Equation (8).

$$U_D = \frac{\sum A_g U_g + \sum A_f U_f + \sum l_g \Psi_g}{\sum A_g + \sum A_f} \tag{8}$$

where

A_f, A_g and l_g are defined in Clause 4;

U_g is the thermal transmittance of the glazing;

U_f is the thermal transmittance of the frame;

Ψ_g is the linear thermal transmittance due to the combined thermal effects of glazing spacer and frame.

In the case of single glazing, the last term of the numerator in Equation (8) shall be taken as zero (no spacer effect) because any correction is negligible.

5.4.2 Doors containing glazing and opaque panels

Key

1 frame (fixed)
2 sash (moveable)
3 opaque panel

Figure 9 — Schematic illustration of door with opaque panel
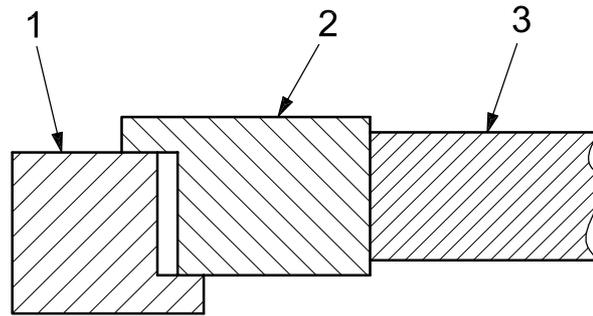
If the door consists of frame, glazing and opaque panels, then Equation (9) shall be used:

$$U_D = \frac{\sum A_g U_g + \sum A_p U_p + \sum A_f U_f + \sum l_g \Psi_g + \sum l_p \Psi_p}{\sum A_g + \sum A_p + \sum A_f} \qquad (9)$$

where

A_p and l_p are defined in Clause 4;

U_p is the thermal transmittance of the opaque panel(s);

Ψ_p is the linear thermal transmittance for opaque panels.

If the door has no glazing, Equation (9) applies with $A_g = 0$ and $l_g = 0$.

Ψ_p may be taken as zero if

— the internal and external facings of the panel are of material with thermal conductivity less than 0,5 W/(m·K), and

— the thermal conductivity of any bridging material at the edges of the panel is less than 0,5 W/(m·K).

In other cases, Ψ_p shall be calculated in accordance with ISO 10077-2.

NOTE 1   Annex D gives typical values of U_f for different types of frame.

NOTE 2   Typical values of Ψ for glazing are given in Annex E.

5.4.3 Door leaves without glazing

The thermal transmittance of opaque door leaves excluding the frame and without inhomogeneities (having different layers only perpendicular to the heat flow direction) can be measured in the heat-flow meter apparatus in accordance with ISO 8301 or in the guarded hot-plate apparatus, in accordance with ISO 8302. Alternatively, EN 12664[1] or EN 12667[2] may be used. Equation (9) is used to calculate the thermal transmittance of the door set, with $A_g = 0$.

Alternatively, the thermal transmittance of door leaves can be calculated in accordance with ISO 6946 provided that the ratio of the thermal conductivities of any two different materials in the door does not exceed 1:5 (screws, nails, and so on are excluded); this method includes the calculation of the maximum relative error which should be less than 10 %.

If the maximum relative error is higher than 10 % or the ratio of the thermal conductivities of the different materials is greater than 1:5, a numerical calculation in accordance with ISO 10077-2 and/or ISO 10211-2 should be carried out.

6 Input data

The thermal transmittance of the frame, U_f, shall be determined with the glazing replaced with a material of thermal conductivity not exceeding 0,04 W/(m·K), by hot box measurement or numerical calculation in accordance with ISO 10077-2. The thermal transmittance of the glazing, U_g, shall be determined in accordance with EN 673, EN 674 or EN 675. Both U_f and U_g thus exclude the thermal interaction between the frame and the glazing (or opaque panel), which is taken into account by the linear thermal transmittance, Ψ_g and/or Ψ_p, either tabulated in this part of ISO 10077 or obtained by numerical calculations in accordance with ISO 10077-2 or by measurement in accordance with EN 12412-2.

Other values used in the basic equations can be obtained from Annex A and ISO 10456, calculated by means of ISO 6946, measured as given in ISO 8301 or ISO 8302, or measured as given in EN 12664[1] or EN 12667[2].

Results obtained for the purposes of comparison of products (declared values) shall be calculated or measured for horizontal heat flow.

Design values should be determined for the actual position and boundary conditions, by including the effect of the inclination of the window in the determination of U_g. However, the U_f and Ψ_g and/or Ψ_p as determined for the window in the vertical position are used for all inclinations of the window.

If measured or calculated data are not available, the values in Annexes B to H may be used.

If the results are to be used for comparison of the performance of different windows, the sources of the numerical values of each parameter shall be identical for each door or window included in the comparison.

7 Report

7.1 Contents of report

The calculation report shall include the following:

— reference to this part of ISO 10077;

— identification of the organization making the calculation;

— date of calculation;

— items listed in 7.2, 7.3 and 7.4.

7.2 Drawing of sections

A technical drawing (preferably on a scale of 1:1) giving the sections of all the different frame parts permitting verification of relevant details such as the following:

— thickness, height, position, type and number of thermal breaks (for metallic frames);

— number and thickness of air chambers (for plastic frames and metal frames where air cavities are associated with a thermal break);

— presence and position of metal stiffening (for plastic frames only);

— thickness of wooden frames and the thickness of plastic and PUR–frame (polyurethane) material;

— thickness of gas spaces, the identification of the gas and the percentage assured to be present;

— type of glass and its thickness or its thermal properties and emissivity of its surfaces;

— thickness and description of any opaque panels in the frame;

— internal projected frame area, $A_{f,i}$, and the external projected frame area, $A_{f,e}$;

— internal developed frame area, $A_{d,i}$, and the external developed frame area, $A_{d,e}$ (only for metallic frames);

— position of the glass spacers or of the edge stiffening for opaque panels;

— description of any shutters.

In the case of metallic frames with pin-point connections, the distance between the pinpoints shall be clearly indicated.

7.3 Drawing of the whole window or door

A drawing of the whole window or door (seen from inside) with the following information:

— glazed area, A_g, and/or opaque panel area, A_p;

— frame area, A_f;

— perimeter length, l_g, of the glazing and/or l_p of the opaque panels.

7.4 Values used in the calculation

The origin of the values used in the calculations shall be indicated.

a) If the informative annexes are used, this shall be clearly stated and reference shall be made to the tables in the annexes.

b) If other sources are used to determine one or more of the U_g, U_f or Ψ values, the sources shall be given. It shall be ascertained that these other sources use the same definitions of the areas, A_g and A_f, and of the perimeter lengths, l_g and l_p.

c) If a glazing not covered by the table in the Annex C is used, a detailed calculation following EN 673 shall be given.

7.5 Presentation of results

The thermal transmittance of the window or door, calculated according to this part of ISO 10077 shall be given to two significant figures.

Annex A
(normative)

Internal and external surface thermal resistances

For typical normal emissivities ($\geqslant 0{,}8$) for the inside and outside surfaces of the glazing, the following values for the surface resistances R_{se} and R_{si} shall be used.

Table A.1 — Surface thermal resistances

Window position	Internal R_{si} m$^2 \cdot$K/W	External R_{se} m$^2 \cdot$K/W
Vertical, or inclination, α, of the glazing to the horizontal such that $90° \geqslant \alpha \geqslant 60°$ (heat flow direction $\pm 30°$ from the horizontal plane)	0,13	0,04
Horizontal, or inclination α of the glazing to the horizontal such that $60° > \alpha \geqslant 0°$ (heat flow direction more than 30° from the horizontal plane)	0,10	0,04

R_{si} for special cases, for example a low-emissivity coating on the outer surface of the interior pane, can be calculated in accordance with EN 673, using the convective coefficient from ISO 6946 for horizontal heat flow if $\alpha > 60°$ and for upwards heat flow if $\alpha \leqslant 60°$.

Annex B
(normative)

Thermal conductivity of glass

In the absence of specific information for the glass concerned the value $\lambda = 1,0$ W/(m·K) should be used.

Annex C
(informative)

Thermal resistance of air spaces between glazing and thermal transmittance of coupled, double or triple glazing

Table C.1 gives some values of the thermal resistance, R_s, of air spaces for double glazing, calculated in accordance with EN 673. The data apply

— for vertical windows,

— for spaces filled with air,

— with both sides uncoated or with one side coated with a low-emissivity layer,

— for a mean temperature of the glazing of 283 K and a temperature difference of 15 K between the two outer glazing surfaces.

For triple glazing, or for inclination other than vertical, the procedure in EN 673 should be used.

Table C.1 — Thermal resistance of unventilated air spaces for coupled and double vertical windows

Thickness of air space	Thermal resistance R_s m²·K/W				
	One side coated with a normal emissivity of				Both sides uncoated
mm	0,1	0,2	0,4	0,8	
6	0,211	0,191	0,163	0,132	0,127
9	0,299	0,259	0,211	0,162	0,154
12	0,377	0,316	0,247	0,182	0,173
15	0,447	0,364	0,276	0,197	0,186
50	0,406	0,336	0,260	0,189	0,179

For wider air layers like in double windows or doors the calculation according to EN 673 does not lead to correct results. For such cases more detailed equations are given in ISO 15099[8], or numerical calculation methods or measurements can be used.

Table C.2 gives the thermal transmittance, U_g, of double and triple glazing filled with different gases, calculated in accordance with EN 673. The values of the thermal transmittance in the table apply to the emissivities and gas concentration given. For individual glazing units, the emissivity and/or gas concentrations can change with time. Procedures for evaluating the effect of ageing on the thermal properties of glazed units are given in EN 1279-1[12] and EN 1279-3[13].

**Table C.2 — Thermal transmittance of double and triple glazing filled
with different gases for vertical glazing**

Glazing				Thermal transmittance for different types of gas space [a] U_g				
Type	Glass	Normal emissivity	Dimensions mm	Air	Argon	Krypton	SF$_6$[b]	Xenon
Double glazing	Uncoated glass (normal glass)	0,89	4-6-4	3,3	3,0	2,8	3,0	2,6
			4-8-4	3,1	2,9	2,7	3,1	2,6
			4-12-4	2,8	2,7	2,6	3,1	2,6
			4-16-4	2,7	2,6	2,6	3,1	2,6
			4-20-4	2,7	2,6	2,6	3,1	2,6
	One pane coated glass	⩽ 0,2	4-6-4	2,7	2,3	1,9	2,3	1,6
			4-8-4	2,4	2,1	1,7	2,4	1,6
			4-12-4	2,0	1,8	1,6	2,4	1,6
			4-16-4	1,8	1,6	1,6	2,5	1,6
			4-20-4	1,8	1,7	1,6	2,5	1,7
	One pane coated glass	⩽ 0,15	4-6-4	2,6	2,3	1,8	2,2	1,5
			4-8-4	2,3	2,0	1,6	2,3	1,4
			4-12-4	1,9	1,6	1,5	2,3	1,5
			4-16-4	1,7	1,5	1,5	2,4	1,5
			4-20-4	1,7	1,5	1,5	2,4	1,5
	One pane coated glass	⩽ 0,1	4-6-4	2,6	2,2	1,7	2,1	1,4
			4-8-4	2,2	1,9	1,4	2,2	1,3
			4-12-4	1,8	1,5	1,3	2,3	1,3
			4-16-4	1,6	1,4	1,3	2,3	1,4
			4-20-4	1,6	1,4	1,4	2,3	1,4
	One pane coated glass	⩽ 0,05	4-6-4	2,5	2,1	1,5	2,0	1,2
			4-8-4	2,1	1,7	1,3	2,1	1,1
			4-12-4	1,7	1,3	1,1	2,1	1,2
			4-16-4	1,4	1,2	1,2	2,2	1,2
			4-20-4	1,5	1,2	1,2	2,2	1,2
Triple glazing	Uncoated (normal) glass	0,89	4-6-4-6-4	2,3	2,1	1,8	1,9	1,7
			4-8-4-8-4	2,1	1,9	1,7	1,9	1,6
			4-12-4-12-4	1,9	1,8	1,6	2,0	1,6
	Two panes coated	⩽ 0,2	4-6-4-6-4	1,8	1,5	1,1	1,3	0,9
			4-8-4-8-4	1,5	1,3	1,0	1,3	0,8
			4-12-4-12-4	1,2	1,0	0,8	1,3	0,8
	Two panes coated	⩽ 0,15	4-6-4-6-4	1,7	1,4	1,1	1,2	0,9
			4-8-4-8-4	1,5	1,2	0,9	1,2	0,8
			4-12-4-12-4	1,2	1,0	0,7	1,3	0,7
	Two panes coated	⩽ 0,1	4-6-4-6-4	1,7	1,3	1,0	1,1	0,8
			4-8-4-8-4	1,4	1,1	0,8	1,1	0,7
			4-12-4-12-4	1,1	0,9	0,6	1,2	0,6
	Two panes coated	⩽ 0,05	4-6-4-6-4	1,6	1,2	0,9	1,1	0,7
			4-8-4-8-4	1,3	1,0	0,7	1,1	0,5
			4-12-4-12-4	1,0	0,8	0,5	1,1	0,5

NOTE   The values of thermal transmittance in the table were calculated using EN 673. They apply to the emissivities and gas concentration given. For individual glazing units the emissivity and/or gas concentrations can change with time. Procedures for evaluating the effect of ageing on the thermal properties of glazed units are given in EN 1279-1[12] and EN 1279-3[13].

[a]   Gas concentration ⩾ 90 %.

[b]   The use of SF$_6$ is prohibited in some jurisdictions.

Annex D
(informative)

Thermal transmittance of frames

D.1 General

The preferred methods of establishing values of thermal transmittance of frames are numerical calculation methods (e.g. finite element, finite difference, boundary element) in accordance with ISO 10077-2 and direct measurements using hot-box methods in accordance with EN 12412-2.

If no other information is available, the values derived from the tables and graphs in this annex can be used for vertical windows in the calculations for the corresponding frame types.

All values given in this annex refer to the vertical position only. Typical values for common types of frames are given in Table D.1 and Figures D.2 and D.4, which can be used in the absence of specific measured or calculated information for the frame concerned. They are based on a large number of measured values as well as mathematically evaluated values determined using numerical calculation methods. The data in Table D.1 and Figure D.2 include the effect of the developed areas; the data in Figure D.4 are derived from surface temperature measurements and a correction id required for the effect of developed areas.

The values of U_f in Table D.1 and Figures D.2 and D.4 cannot be used for sliding windows but the principle of Equation (1) can be used.

Future development should not be impeded by tabulated U_f values. Values for frames that are not described in the tables should be determined by measurements or calculations.

Especially in the case of aluminium profiles with thermal breaks, there is the problem that the thermal transmittance of the frame is influenced by different construction characteristics, such as

— distance, d, between the aluminium sections,

— width, b, of the material of the thermal break zones,

— conductivity of the thermal break material,

— ratio of the width of the thermal break to the projected frame width.

A thermal break can be considered as such only if it completely separates the metal sections on the cold side from the metal sections on the warm side.

The values in this annex are based on $R_{si} = 0,13$ m^2·K/W and $R_{se} = 0,04$ m^2·K/W.

It is common practice to produce "profile systems" comprising a large number of different frames, having a wide range of geometric shapes but having similar thermal properties. This is because in these groups of frames, the important parameters, such as the size, material and design of the thermal break, are the same. The thermal transmittance of a profile or profile combination of a "profile system" can be evaluated by
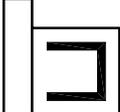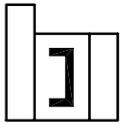
— using the highest value of U_f of the profiles or profile combinations within the profile system, or

— using trend lines that show the relationship between U_f and defined geometrical characteristics.

In the latter case, the data points for the trend line are evaluated on selected profile cross-sections, taken from the profile system in question. Detailed procedures are described in References [3], [4] and [5].
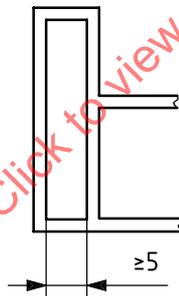
D.2 Plastic frames

Table D.1 gives approximate values for plastic frames with metal reinforcements. If no other data are available, the values in Table D.1 can also be used for frames without metal reinforcements.

Table D.1 — Thermal transmittances for plastic frames with metal reinforcements

| Frame material	Frame type		U_f W/(m²·K)
Polyurethane	with metal core thickness of PUR $\geqslant$ 5 mm		2,8
PVC-hollow profiles [a]	two hollow chambers external	internal	2,2
	three hollow chambers external	internal	2,0
[a] With a distance between wall surfaces of each hollow chamber of at least 5 mm (refer to Figure D.1).			

Dimensions in millimetres

Figure D.1 — Hollow chamber in plastic frame

Other plastic profile sections should be measured or calculated.

D.3 Wood frames

Values for wood frames can be taken from Figure D.2. For U_f, the values correspond to a moisture content of 12 %. For definition of the thickness of the frame, see Figure D.3.
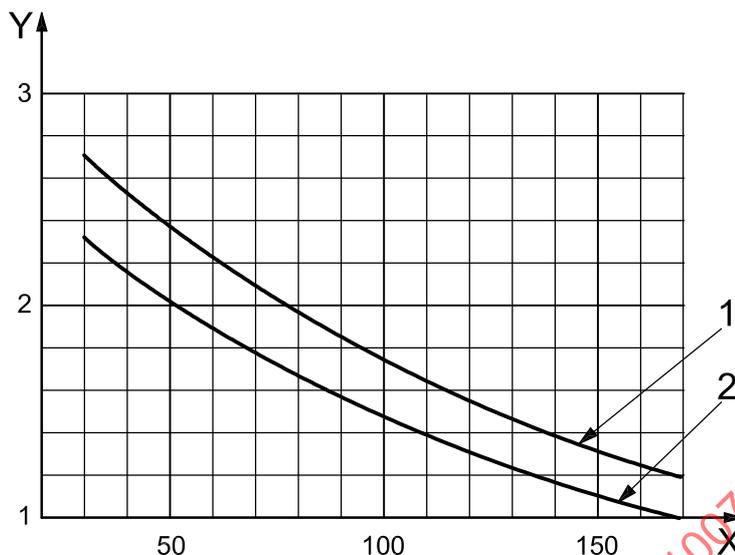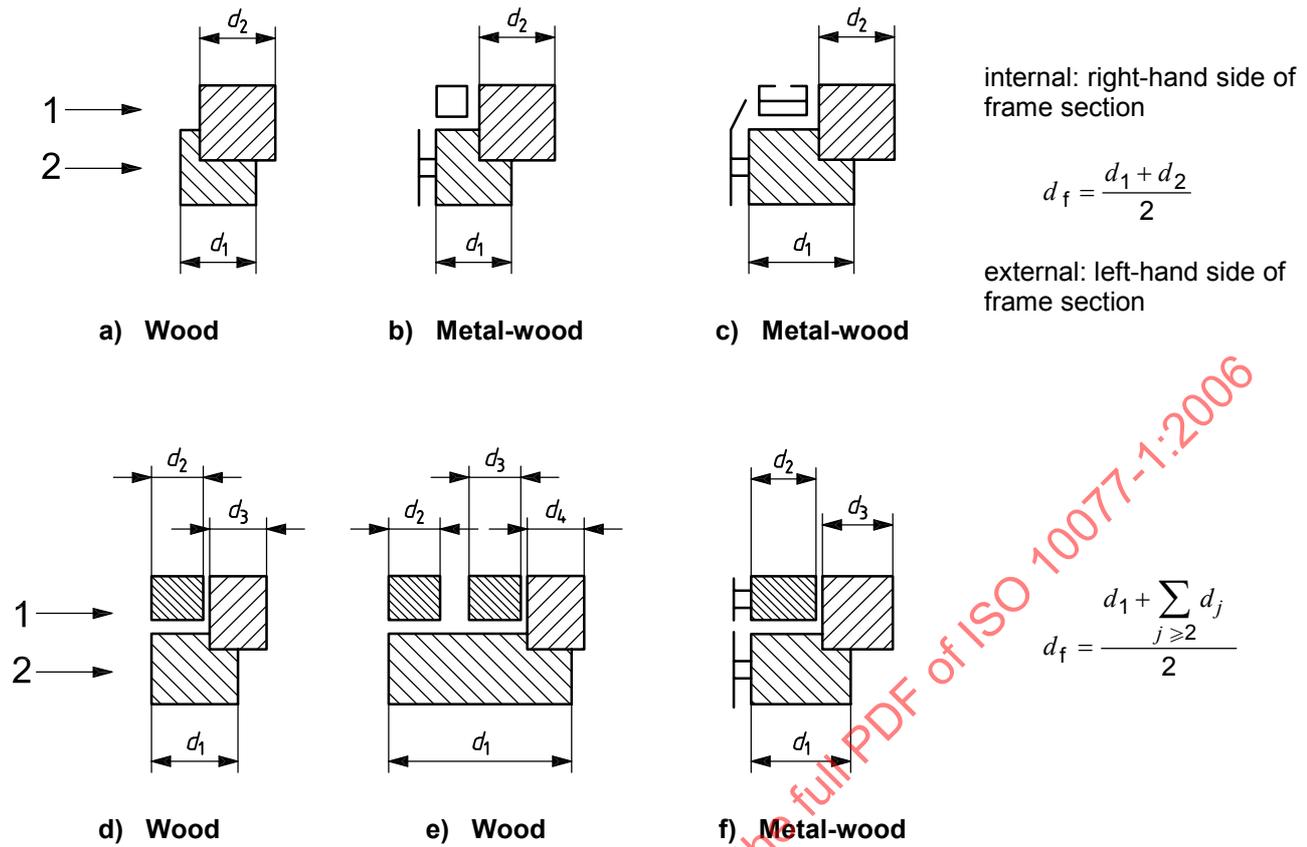
Key

X   thickness of frame, d_f, expressed in millimetres

Y   thermal transmittance of frame, U_f, in W/(m²·K)

1   hardwood (density 700 kg/m³), $\lambda = 0,18$ W/(m·K)

2   softwood (density 500 kg/m³), $\lambda = 0,13$ W/(m·K)

Figure D.2 — Thermal transmittances for wooden frames and metal-wood frames (see Figure D.3) depending on the frame thickness, d_f

internal: right-hand side of frame section

$$d_f = \frac{d_1 + d_2}{2}$$

external: left-hand side of frame section

a) Wood b) Metal-wood c) Metal-wood

d) Wood e) Wood f) Metal-wood

$$d_f = \frac{d_1 + \sum\limits_{j \geqslant 2} d_j}{2}$$

Key

1 sash
2 frame

Figure D.3 — Definition of the thickness, d_f, of the frame for various window systems

D.4 Metal frames

The thermal transmittance of metal frames can be determined by measurement using hot box methods in accordance with EN 12412-2 or by numerical calculation in accordance with ISO 10077-2. Values obtained by such methods should be used when available, in preference to the method given in this annex.

If such data are not available, values of U_f can be obtained by the following procedure:

— metal frames without a thermal break,

— metal frames with thermal breaks corresponding to the sections illustrated in Figures D.5 and D.6, subject to restrictions on the thermal conductivity and widths of the thermal breaks.

For metal frames without a thermal break, $R_f = 0$.

For metal frames with thermal breaks, take R_f from line 2 in Figure D.4.
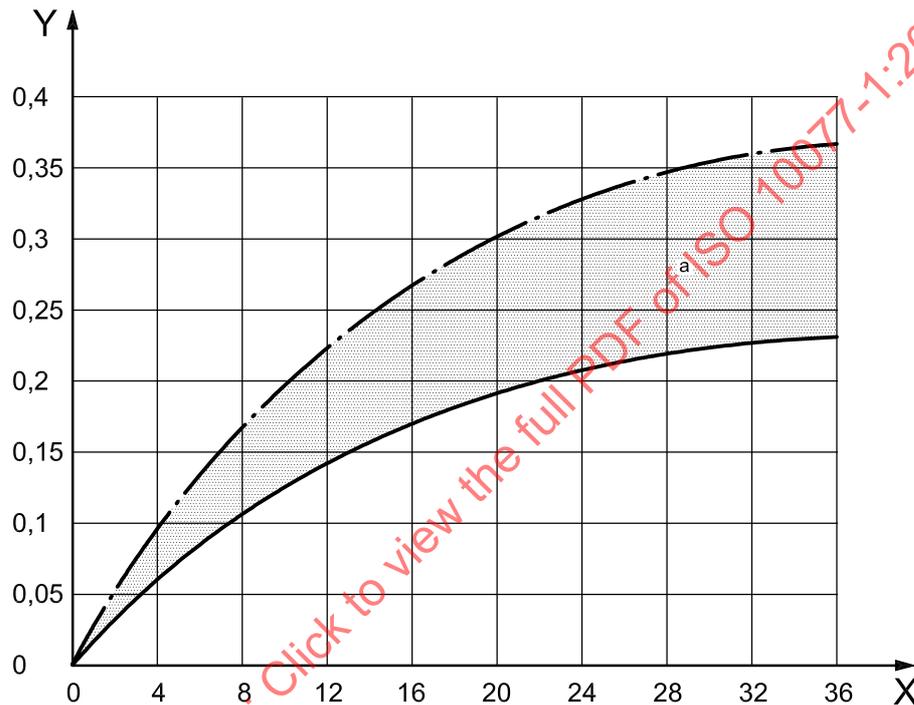
Key

X   smallest distance, d, between opposite metal sections, expressed in millimetres

Y   thermal resistance, R_f, of frame, expressed in m²·K/W

a   The shaded area indicates the range of values obtained from many measurements on frames carried out in several European countries, derived from the surface temperature difference across the frame.

Figure D.4 — Values of R_f for metal frames with thermal break

The thermal transmittance, U_f, of the frame is given by Equation (D.1):

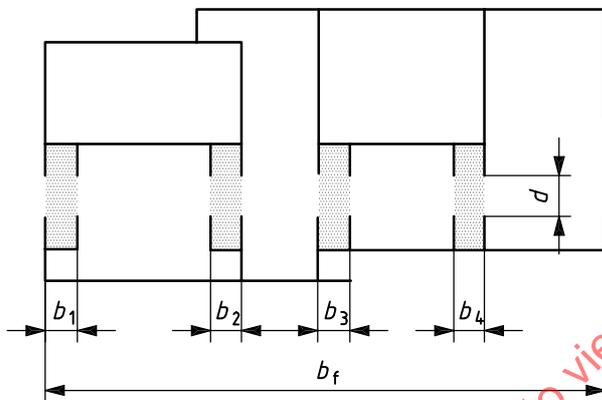$$U_f = \frac{1}{R_{si} A_{f,i}/A_{f,di} + R_f + R_{se} A_{f,e}/A_{f,de}}$$

(D.1)

where

$A_{f,di}, A_{f,de}, A_{f,i}, A_{f,e}$ are the areas as defined in Clause 4, expressed in square metres;

R_{si} is the appropriate internal surface resistance of the frame, in m²·K/W;

R_{se} is the appropriate external surface resistance of the frame, in m²·K/W;

R_f is the thermal resistance of the frame section, in m²·K/W.

Thermal conductivity, λ, of thermal break materials such that

$0,2 < \lambda \leqslant 0,3$ W/(m·K)

where

d is the smallest distance between opposite aluminium sections of the thermal break;

b_j is the width of thermal break j;

b_f is the width of the frame.

$\sum_j b_j \leqslant 0,2\, b_f$

Figure D.5 — Section type 1 — Thermal break with a thermal conductivity less than 0,3 W/(m·K)

Thermal conductivity, λ, of thermal break materials such that
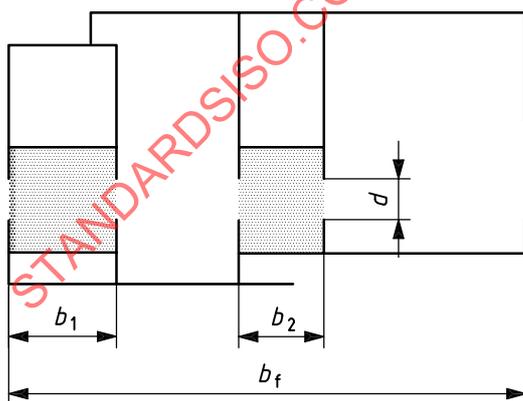
$0,1 < \lambda \leqslant 0,2$ W/(m·K)

where

d is the smallest distance between opposite aluminium sections of the thermal break;

b_j is the width of thermal break j;

b_f is the width of the frame.

$\sum_j b_j \leqslant 0,3\, b_f$

Figure D.6 — Section type 2 — Thermal break with a thermal conductivity less than 0,2 W/(m·K)

If the thermal conductivity of the thermal break material is less than 0,1 W/(m·K), the definition in Figure D.6 is not valid.

Annex E
(normative)

Linear thermal transmittance of frame/glazing junction

E.1 General

The thermal transmittance of the glazing, U_g, is applicable to the central area of the glazing and does not include the effect of the glass spacers at the edge of the glazing. On the other hand, the thermal transmittance of the frame, U_f, is applicable in the absence of the glazing. The linear thermal transmittance, Ψ_g, describes the additional heat conduction due to the interaction between frame, glazing and spacer, and is affected by the thermal properties of each of these components.

The preferred method of establishing values of linear thermal transmittance is by numerical calculation in accordance with ISO 10077-2. E.2 and E.3 give default values of Ψ_g for typical combinations of frames, glazing and spacers that can be used when the results of a detailed calculation are not available.

NOTE   For single glazing, $\Psi_g = 0$.

E.2 Aluminium and steel spacers

Table E.1 indicates values of Ψ_g for glass spacers of aluminium or non-alloy steel for a specific range of types of frames and glazing.

Table E.1 — Values of linear thermal transmittance for common types of glazing spacer bars (e.g. aluminium or steel)

Frame type	Linear thermal transmittance for different types of glazing Ψ_g	
	Double or triple glazing uncoated glass air- or gas-filled	Double [a] or triple [b] glazing low-emissivity glass air- or gas-filled
Wood or PVC	0,06	0,08
Metal with a thermal break	0,08	0,11
Metal without a thermal break	0,02	0,05
[a] One pane coated for double glazed.		
[b] Two panes coated for triple glazed.		

E.3 Thermally improved spacers

For the purposes of this annex, a thermally improved spacer is defined by the following criterion in Equation (E.1):

$$\sum (d \times \lambda) \leqslant 0,007 \tag{E.1}$$

where

d is the thickness of the spacer wall, expressed in metres;

λ is the thermal conductivity of the spacer material, in W/(m·K).

The summation applies to all heat flow paths parallel to the principal heat flow direction, the thickness, d, being measured perpendicular to the principal heat flow direction; see Figure E.1. Values of thermal conductivity for spacer materials should be taken from ISO 10456 or ISO 10077-2.

Where the criterion in Equation (E.1) is not applicable because of the nature of the construction of the spacer, for example, where one or more of the heat flow paths comprises a combination of materials of different thermal conductivity, the linear thermal transmittance should be calculated in accordance with ISO 10077-2.
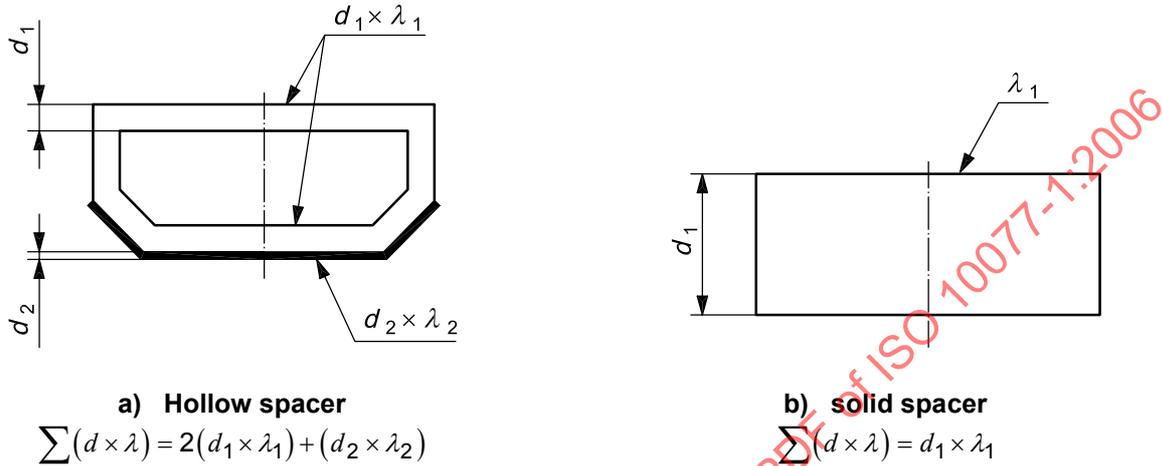

a) Hollow spacer

$$\sum (d \times \lambda) = 2(d_1 \times \lambda_1) + (d_2 \times \lambda_2)$$

b) solid spacer

$$\sum (d \times \lambda) = d_1 \times \lambda_1$$

Figure E.1 —Examples of determination of criterion for thermally improved spacers

Table E.2 gives values for thermally improved spacers that conform with the criterion in Equation (E.1).

Table E.2 — Values of linear thermal transmittance for glazing spacer bars
with improved thermal performance

Frame type	Linear thermal transmittance for different types of glazing with improved thermal performance Ψ_g	
	Double or triple glazing uncoated glass air- or gas-filled	Double [a] or triple [b] glazing low emissivity glass air- or gas-filled
Wood or PVC	0,05	0,06
Metal with a thermal break	0,06	0,08
Metal without a thermal break	0,01	0,04
[a] One pane coated for double glazed. [b] Two panes coated for triple glazed.		

Annex F
(informative)

Thermal transmittance of windows

Tables F.1 and F.2 give typical values calculated by the method in this part of ISO 10077 using linear thermal transmittances from Annex E for normal types of glazing spacer bars (see Table E.1). Tables F.3 and F.4 give corresponding values for spacer bars with improved thermal performance (see Table E.2).

The data in Tables F.1 to F.4 are calculated for windows

— positioned vertically,

— of dimensions 1,23 m by 1,48 m,

— with frame area equal to 30 % and 20 % of the total window area,

— with glazing and frame types as follows:

— glazing: $U_g \geqslant 2,1$: uncoated glass; $U_g \leqslant 2,0$: low emissivity glass,

— frame: $U_f = 7,0$: metal without thermal break; $2,2 \leqslant U_f \leqslant 3,8$: metal with thermal break; $U_f \leqslant 2,0$: wood or PVC,

— with a single light.

Values for windows of other sizes, positioned other than vertically, with other frame area fractions or with other frame/glazing permutations can be evaluated by means of the equations in the main part of this part of ISO 10077.