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Second edition
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Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method —

Part 1: Complete windows and doors

Isolation thermique des fenêtres et portes — Détermination de la transmission thermique par la méthode à la boîte chaude —

Partie 1: Fenêtres et portes complètes

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ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

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Foreword

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

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

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

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

ISO 12567-1 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 1, *Test and measurement methods*.

This second edition cancels and replaces the first edition (ISO 12567-1:2000), which has been technically revised.

ISO 12567 consists of the following parts, under the general title *Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method*:

— *Part 1: Complete windows and doors*

— *Part 2: Roof windows and other projecting windows*[1)]

1) It is intended that, upon revision, the main element of the title of Part 2 will be aligned with the main element of the title of Part 1.

Introduction

The method specified in this part of ISO 12567 is based on ISO 8990. It is designed to provide both standardized tests, which enable a fair comparison of different products to be made, and specific tests on products for practical application purposes. The former specifies standardized specimen sizes and applied test criteria.

The determination of the aggregate thermal transmittance is performed for conditions which are similar to the actual situation of the window and door in practice.

Thermal performance of windows and doors — Determination of thermal transmittance by the hot-box method —

Part 1:
Complete windows and doors

1 Scope

This part of ISO 12567 specifies a method to measure the thermal transmittance of a door or window system. It is applicable to all effects of frames, sashes, shutters, blinds, screens, panels, door leaves and fittings.

It is not applicable to

— edge effects occurring outside the perimeter of the specimen,

— energy transfer due to solar radiation on the specimen,

— effects of air leakage through the specimen, and

— roof windows and projecting products, where the external face projects beyond the cold side roof surface.

NOTE For roof windows and projecting units, see the procedure given in ISO 12567-2.

Annex A gives methods for the calculation of environmental temperatures.

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 8990:1994, *Thermal insulation — Determination of steady-state thermal transmission properties — Calibrated and guarded hot box*

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

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

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

IEC 60584-1, *Thermocouples — Part 1: Reference tables*

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 8990 and ISO 9288 apply.

3.2 Symbols

For the purposes of this document, the physical quantities given in ISO 7345 and ISO 9288 apply, together with those given in Tables 1 and 2.

Table 1 — Symbols and units

Symbol	Physical quantity	Unit
A	Area	m^2
d	Thickness (depth)	m
F	Fraction	—
f	View factor	—
h	Surface coefficient of heat transfer	$W/(m^2 \cdot K)$
H	Height	m
L	Perimeter length	m
q	Density of heat flow rate	W/m^2
R	Thermal resistance	$m^2 \cdot K/W$
T	Thermodynamic temperature	K
U	Thermal transmittance	$W/(m^2 \cdot K)$
v	Air speed	m/s
w	Width	m
α	Radiant factor	—
ΔT, $\Delta \theta$	Temperature difference	K
ε	Total hemispherical emissivity	—
θ	Temperature	°C
λ	Thermal conductivity	$W/(m \cdot K)$
σ	Stefan-Boltzmann constant	$W/(m^2 \cdot K^4)$
Φ	Heat flow rate	W
Ψ	Linear thermal transmittance	$W/(m \cdot K)$

Table 2 — Subscripts

Subscript	Significance
b	Baffle
c	Convection (air)
cal	Calibration
e	External, usually cold side
i	Internal, usually warm side
in	Input
m	Measured
me	Mean
n	Environmental (ambient)
ne	Environmental (ambient) external
ni	Environmental (ambient) internal
p	Reveal of surround panel
r	Radiation (mean)
s	Surface
se	Exterior surface, usually cold side
si	Interior surface, usually warm side
sp	Specimen
st	Standardized
sur	Surround panel
t	Total
W	Window
WS	Window with closed shutter or blind
D	Door

Table 3 — Symbols for uncertainty analysis for hot boxes

A_{sp}	Test specimen projected area	m^2
A_{sur}	Surround panel projected area	m^2
H_{sp}	Test specimen height	m
H_{sur}	Surround panel height	m
λ_{sur}	Surround panel thermal conductivity	W/m·K
d_{sp}	Test specimen thickness (depth)	m
d_{sur}	Surround panel thickness (depth)	m
P	Confidence level	%
Φ_{EXTR}	Extraneous heat transfer in the metering chamber	W
$\Phi_{\text{FL,sp}}$	Test specimen flanking heat transfer	W
Φ_{IN}	Total power input to the metering chamber	W
Φ_{sp}	Heat transfer through the test specimen	W
Φ_{sur}	Heat transfer through the surround panel	W
R	Dependent variable	
s_{y}	Sample standard deviation of measured values of variable	y
θ_{n}	Hot-box ambient air temperature	°C
θ_{e}	Cold side (climatic chamber) external air temperature	°C
θ_{i}	Warm side (metering room) internal air temperature	°C
$t_{\text{v,P}}$	t value of v's degree of freedom and P's confidence level	
U_{CTS}	Calibration transfer standard (CTS) thermal transmittance	$W/m^2 \cdot K$

Table 3 (*continued*)

U_{sp}	Test specimen thermal transmittance	W/m²·K
U_{st}	Standardized test specimen thermal transmittance	W/m²·K
V	Metering chamber wall thermopile voltage	mV
w_{sp}	Test specimen width	m
w_{sur}	Surround panel width	m
x_i	Independent variable, i = 1, 2, …, N	
y_c	Calculated value of dependent variable y	
z	Independent variable	
θ_{AMB}	External ambient temperature	°C
$\theta_{me,sur}$	Surround panel mean temperature	°C
σ	Stefan-Boltzmann constant, 5.669×10^{-8}	$W/m^2 \cdot K^4$
Δ	Uncertainty, difference	
$\delta\theta$	Temperature, difference	°C
$\delta\theta_{ie}$	Air temperature difference between warm and cold side chambers	°C
∂	Partial derivative	
υ	Degree of freedom	
$\delta\theta_{sur}$	Surround panel surface temperature difference	°C
The uncertainty analysis for hot boxes is given in Annex F.		

4 Principle

The thermal transmittance, U, of the specimen is measured by means of the calibrated or guarded hot-box method in accordance with ISO 8990.

The determination of the thermal transmittance involves two stages. Firstly, measurements are made on two or more calibration panels with accurately known thermal properties, from which the surface coefficient of the heat transfer (radiative and convective components) on both sides of the calibration panel with surface emissivities on average similar to those of the specimen to be tested and the thermal resistance of the surround panel are determined. Secondly, measurements are made with the window or door specimens in the aperture and the hot-box apparatus is used with the same fan settings on the cold side as during the calibration procedure.

The surround panel is used to keep the specimen in a given position. It is constructed with outer dimensions of appropriate size for the apparatus, having an aperture to accommodate the specimen (see Figures 1 to 4).

The principal heat flows through the surround panel and the calibration panel (or test specimen) are shown in Figure 5. The boundary edge heat flow due to the location of the calibration panel in the surround panel is determined separately by a linear thermal transmittance, Ψ.

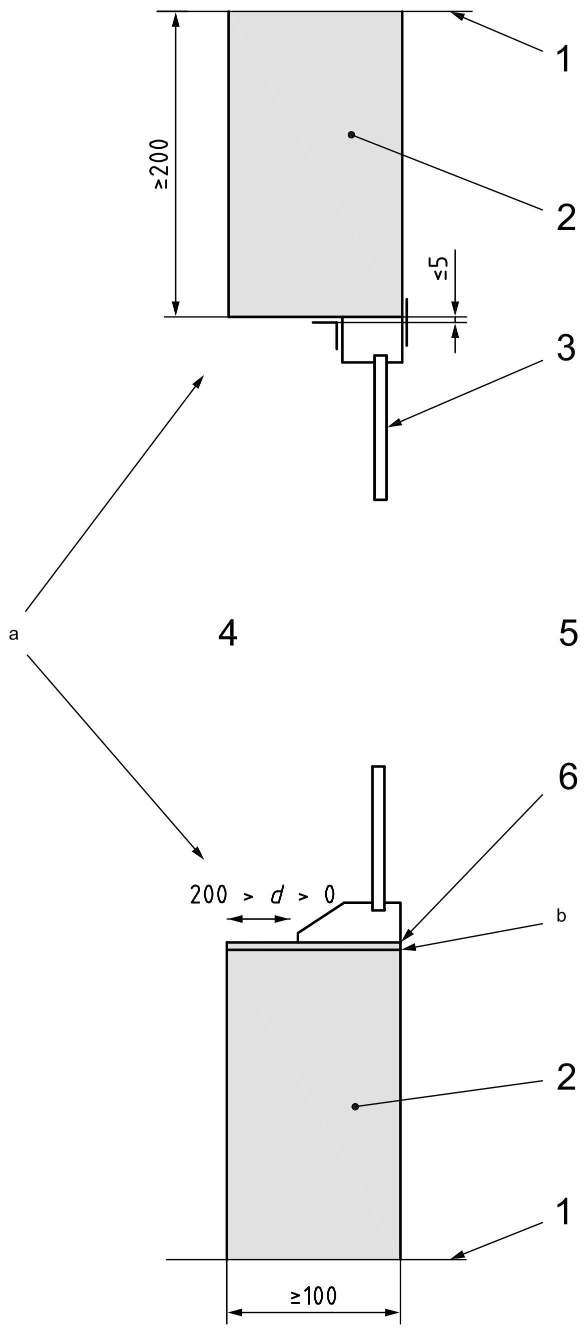
The procedure in this part of ISO 12567 includes a correction for the boundary edge heat flow, such that standardized and reproducible thermal transmittance properties are obtained.

The magnitude of the boundary edge heat flow as a function of geometry, calibration panel thickness and thermal conductivity is determined by tabulated values given in Annex B or is calculated in accordance with ISO 10211.

Measurement results are corrected to standardized surface heat transfer coefficients by an interpolation or analytical iteration procedure, derived from the calibration measurements.

Measurements are taken (e.g. pressure equalization between the warm and cold side or sealing of the joints on the inside) to ensure that the air permeability of the test specimen does not influence the measurements.

Dimensions in millimetres



The total gap width between the top and bottom of the specimen and the surround panel aperture shall not exceed 5 mm. It shall be sealed with non-metallic tape or mastic material. The total gap width on both sides between the specimen and the surround panel aperture shall not exceed 5 mm.

Key

1 border of metering area

2 surround panel, $\lambda \leqslant$ 0,04 W/(m·K)

3 glazing

4 cold side

5 warm side

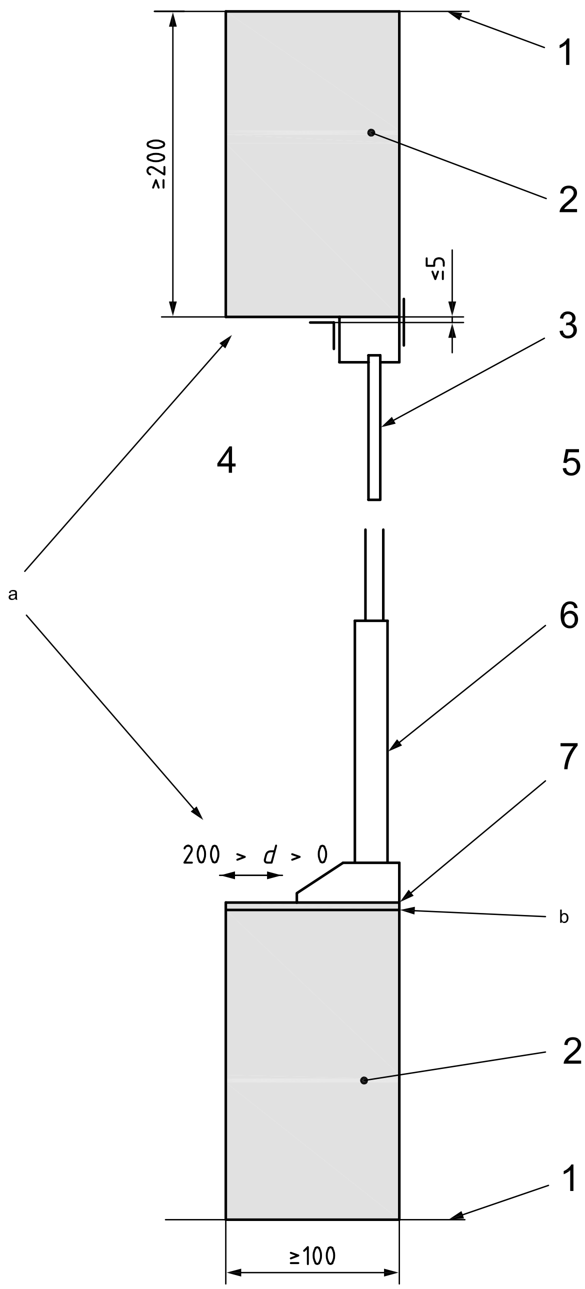
6 flush sill

[a] Metering area, centrally located in the surround panel, is recommended.

[b] Use fill material with same thermal properties as surround panel core.

Figure 1 — Window system in surround panel

Dimensions in millimetres



The total gap width between the top and bottom of the specimen and the surround panel aperture shall not exceed 5 mm. It shall be sealed with non-metallic tape or mastic material. The total gap width on both sides between the specimen and the surround panel aperture shall not exceed 5 mm.

Key

1 border of metering area

2 surround panel, $\lambda \leqslant 0,04$ W/(m·K)

3 infill (glass, panel)

4 cold side

5 warm side

6 door leaf

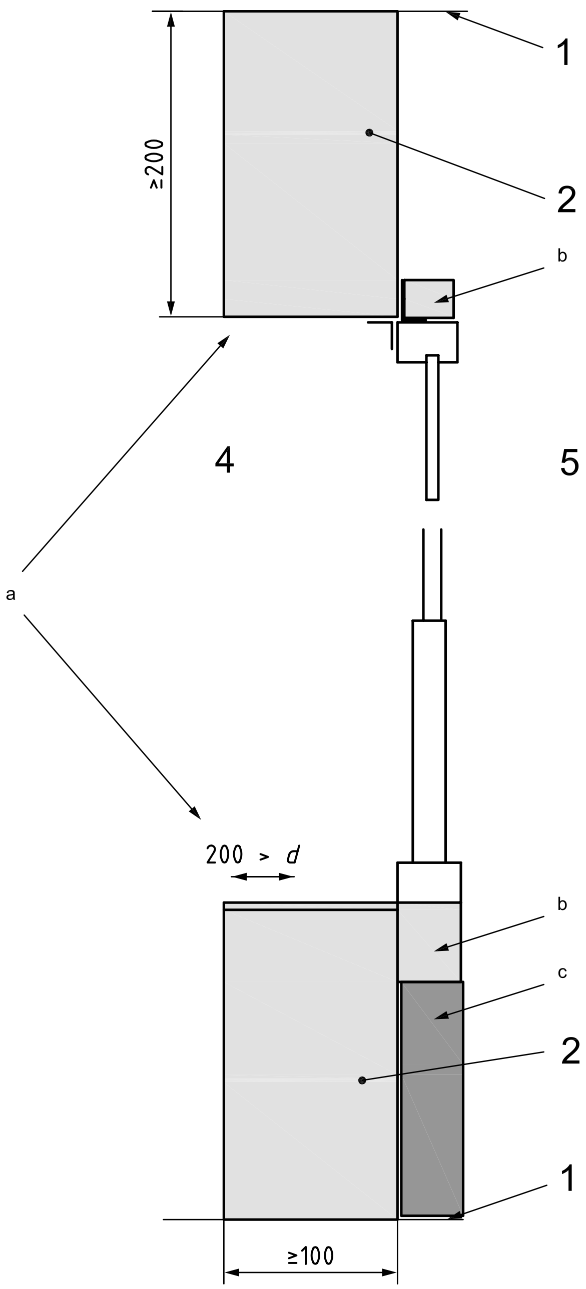
7 flush frame/threshold

a Metering area, centrally located in the surround panel, is recommended.

b Use fill material with same thermal properties as surround panel core.

Figure 2 — Door system in surround panel — Insert mounting

Dimensions in millimetres



Key

1 border of metering area

2 surround panel, λ ⩽ 0,04 W/(m·K)

4 cold side

5 warm side

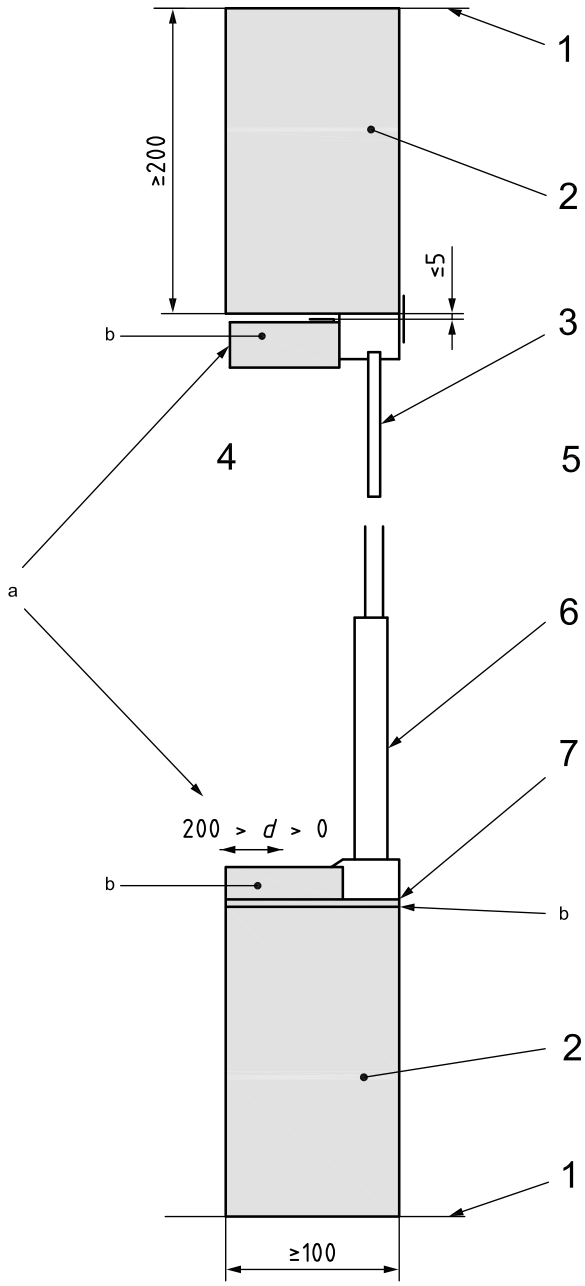
[a] Metering area, centrally located in the surround panel, is recommended.

[b] Material with same thermal properties as surround panel core, minimum size equal to the frame width.

[c] Supporting structure for taking the load of the door.

Figure 3 — Door system in surround panel — Warm surface mounting

Dimensions in millimetres



Key

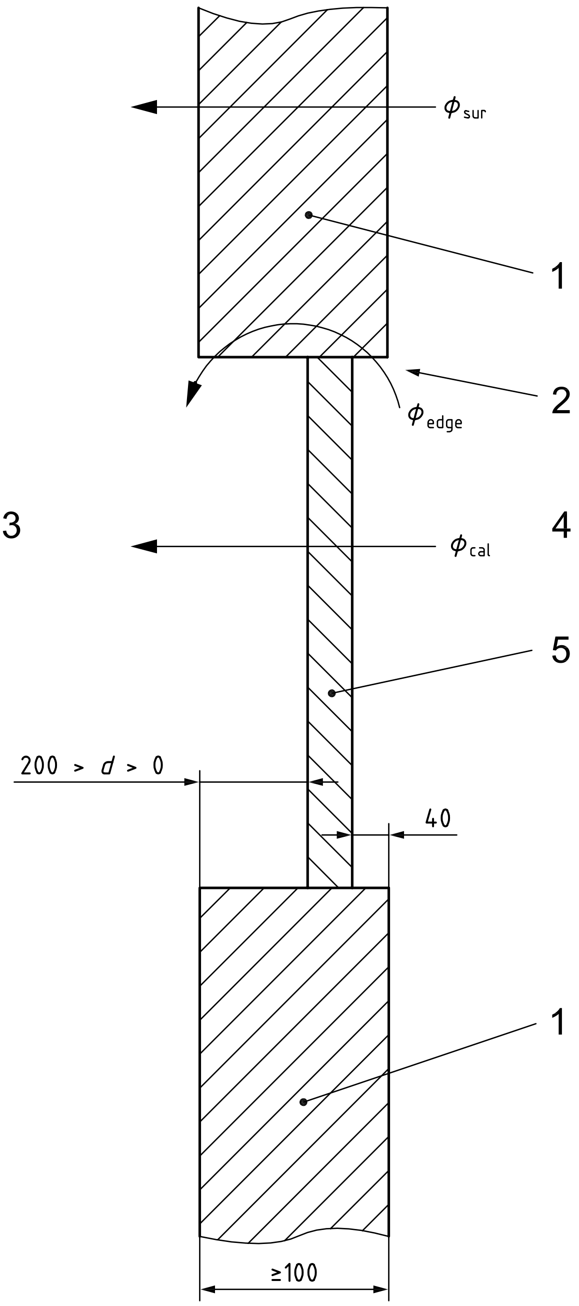
1 border of metering area
2 surround panel, $\lambda \leqslant 0{,}04$ W/(m·K)
3 infill (glass, panel)
4 cold side
5 warm side
6 door leaf
7 flush frame/threshold

[a] Metering area, centrally located in the surround panel, is recommended.

[b] Use fill material with same thermal properties as surround panel core.

Figure 4 — Door system in surround panel — Inside mounting

Dimensions in millimetres



Key

1 surround panel
2 boundary effect
3 cold side
4 warm side
5 calibration panel

Figure 5 — Mounting of calibration panel in aperture

5 Requirements for test specimens and apparatus

5.1 General

The construction and operation of the apparatus shall comply with the requirements specified in ISO 8990, except where modified by this part of ISO 12567. To make heat transfer measurements on the specimen, the specimen shall be mounted in a suitable surround panel and the heat flow shall be deduced through it by subtracting that through the surround panel from the total heat input. Also, the test element and the surround panel are usually of different thickness, such that there is disturbance of heat flow paths and temperatures in the region of the boundary between the two. The test shall be carried out such that edge corrections can be applied.

5.2 Surround panels

The surround panel acts as an idealized wall with high thermal resistance and holds the window or door in the correct position and separates the warm box from the cold box. The surround panel shall be large enough to cover the open face of the guard box in the case of a guarded hot-box apparatus or the open face of the hot box in the case of a calibrated hot-box apparatus.

The surround panel shall be not less than 100 mm thick or the maximum thickness of the specimen, whichever is the greater, and it shall be constructed with core material of stable thermal conductivity not greater than 0,04 W/(m·K). An appropriate aperture shall be provided to accommodate the calibration panel or test specimen (see Figures 1, 2, 3 and 4). Sealed plywood facing or plastic sheet on either side of the surround panel to provide rigidity is permitted. No material of thermal conductivity higher than 0,04 W/(m·K) (other than non-metallic thin tape) shall bridge the aperture. The surfaces of the surround panel and baffle plates shall have a high emissivity ($> 0,8$).

5.3 Test specimens

For general applications, specimen sizes may be typical of those found in practice. To ensure consistency of measurement, the specimen should be located as follows.

The window system shall fill the surround panel aperture. The internal frame face shall be as close to the face of the surround panel as possible, but no part shall project beyond the surround panel faces on either the cold or warm sides, except for handles, rails, fins or fittings which normally project (see Figure 1).

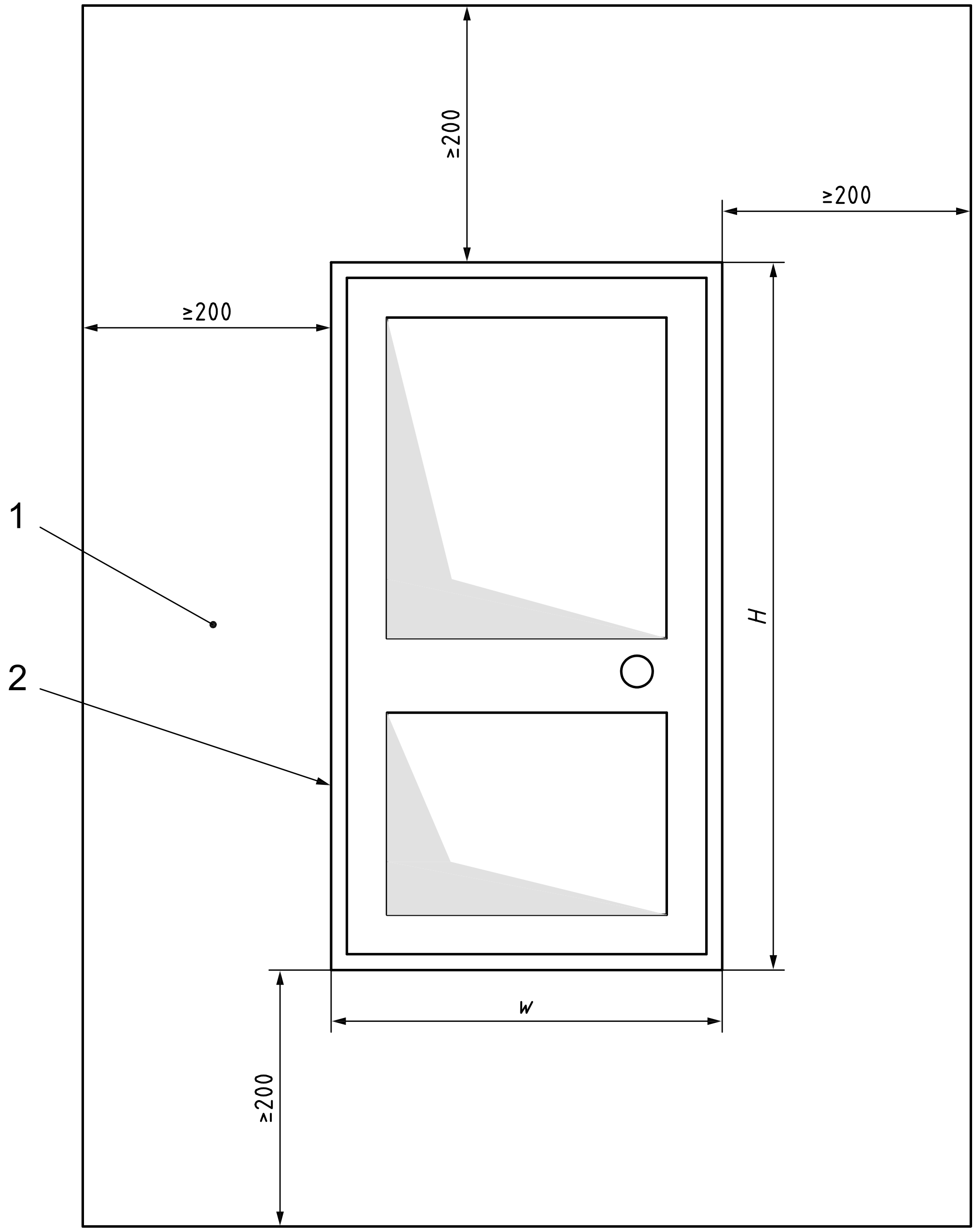
The door system may be mounted on either inside the surround panel (see Figures 2 and 4) or on the warm face (see Figure 3), according to the instructions and specifications given by the manufacturer.

It is recommended that the aperture be placed centrally in the surround panel and at least 200 mm from the inside surfaces of the cold and hot boxes, in order to avoid or limit edge heat flow corrections related to the perimeter of the surround panel (see Figure 6).

For standardized test applications, the overall sizes recommended are indicated in Table 4, or they shall conform to the size required by national standards or other regulations.

In any case, the area of aperture shall be not less than 0,8 m^2, for reasons of accuracy. The perimeter joints between the surround panel and the specimen shall be sealed on both sides with tape, caulking or mastic material.

Dimensions in millimetres



Key

1 surround panel

2 test specimen

Figure 6 — Surround panel with test specimen

Table 4 — Recommended specimen sizes

Component	Height mm	Width mm
Window	1 480 (with a relative tolerance of – 25%)	1 230 (with a relative tolerance of ± 25%)
Window	2 180 (with a relative tolerance of ± 25%)	1 480 (with a relative tolerance of + 25%)
Door (leaf or doorset)	2 180 (with a relative tolerance of ± 25%)	1 230 (with a relative tolerance of ± 25%)
Door (leaf or doorset)	2 180 (with a relative tolerance of ± 25%)	2 000 (with a relative tolerance of ± 25%)

5.4 Calibration panels

Calibration panels shall be of a size similar to the test specimen (within ± 40 % in height and width of the test specimen). They are required to set up specified test conditions, to determine the surface coefficients of heat transfer and to establish the thermal resistance of the surround panel.

At least two calibration panels shall be built, which fulfil the following requirements.

a) The core material of the calibration panel shall be made of homogeneous material with known thermal conductivity or thermal resistance. The material used shall not be prone to ageing effects.

b) The nature of the surface of the calibration panel shall be similar to that of the test specimen. The emissivity of the surface shall be known (e.g. normal float glass) or shall be measured in accordance with EN 12898.

c) The calibration panels shall cover the likely range of test specimen density of heat flow rate. The use of two calibration panels with different total thickness is recommended:

   1) total thickness approximately 20 mm;

   2) total thickness approximately 60 mm.

More details and guidance on how to build up the calibration panels are given in Annex C.

The thermal resistance of the insulating material used in the panels shall be measured for mean temperatures in the range 0 °C to 15 °C, using a guarded hot plate or heat flow meter apparatus in accordance with ISO 8301 or ISO 8302, respectively. Alternatively, calibration panels may be used with certified properties from an accredited source. In any case, the calibration panels shall be mounted in the surround panel aperture 40 mm from the warm face as shown in Figure 3.

5.5 Temperature measurements and baffle positions

For calibration measurements, the warm and cold side surface temperatures shall be measured or calculated. (For calibration panel design and sensor mounting, see Annex C.) A minimum of nine positions at the centre of a rectangular grid of equal areas shall be used on the calibration panel and eight positions on the surround panel (Figure 5). No temperature sensors shall be closer than 100 mm to the edge of the calibration panel. Temperature sensors and recording systems shall be accurately calibrated. The recommended temperature sensor to be used for surface temperature measurement is the type T thermocouple (copper/constantan) in accordance with IEC 60584-1 made from wire with diameter not greater than 0,3 mm. They shall be fixed to the surface using adhesive or adhesive tape with an outer surface of high emissivity (> 0,8). If alternative sensors are used, they shall be at least as accurate as the above-mentioned, not subject to drift or hysteresis, and shall be as small as possible to avoid disturbance of the temperature field near the point of contact. Suitability can be investigated with an infrared camera under heat flow conditions similar to the required operating specifications. The uncertainty in the surface temperature measurements shall be experimentally determined.

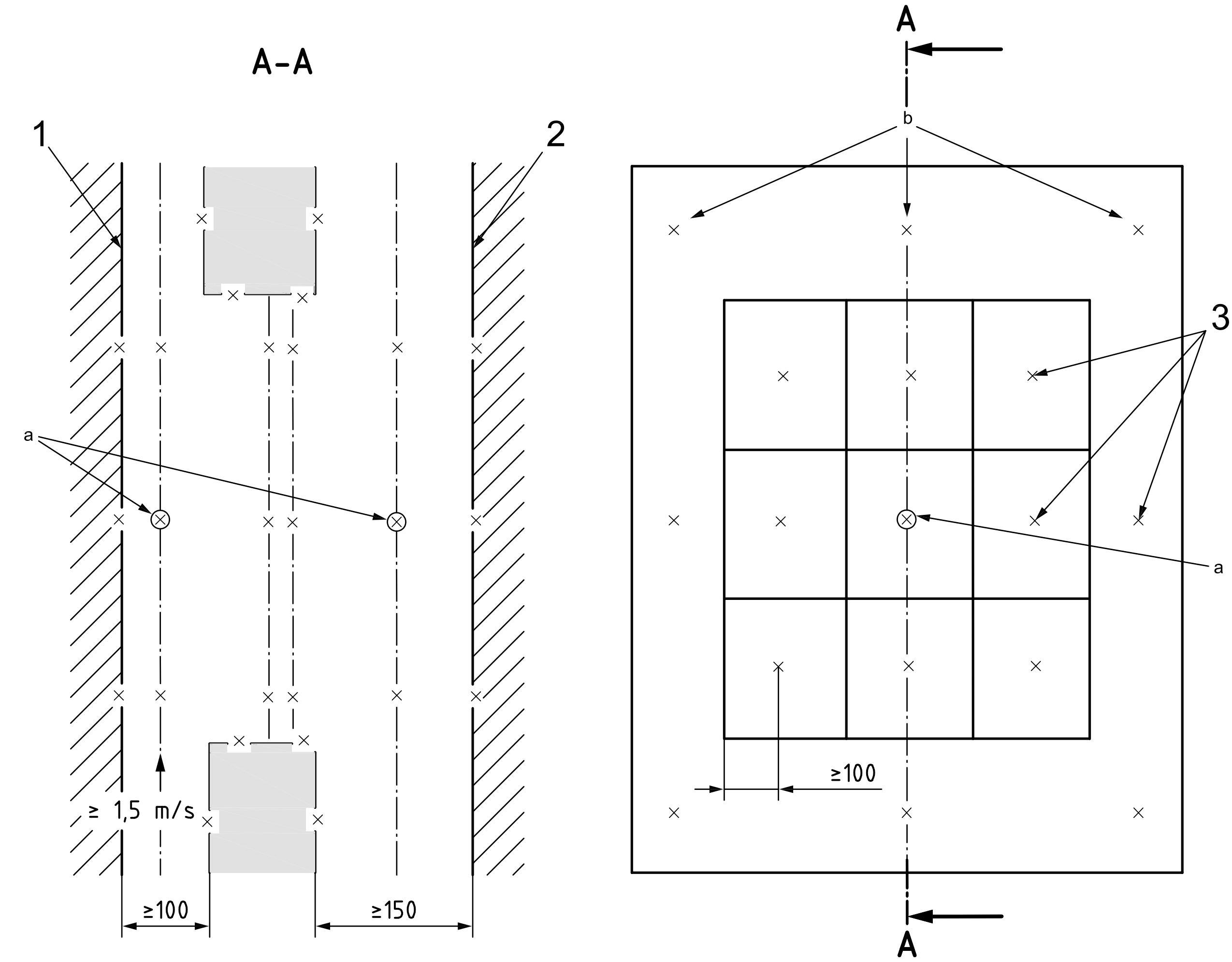
It is recommended that the same layout of the surface temperature grid on the calibration panel be used (a minimum of nine) for air temperature and baffle plate measurements.

For natural convection on the warm side, the distance between the baffle and the plane of the warm face of the surround panel shall be not less than 150 mm and on the cold face not less than 100 mm for appropriate air speed (not less than 1,5 m/s during the first calibration test, see 5.6 and 6.2.2.1). Air temperatures shall be measured on each side outside the boundary layer (see Figure 7).

5.6 Air flow measurement

The cold side air speed shall be measured at a position that represents the free stream condition. For either vertical or horizontal flow patterns, it is essential that the sensor not be in the test specimen surface boundary layers or in the wake of any projecting fitting. If a small fan is used on the warm side, an air speed sensor (see Figure 7) shall be used to verify that the air speed representing natural convection prevails (less than 0,3 m/s).

Dimensions in millimetres



Key

1 cold-side baffle

2 warm-side baffle

3 temperature sensors

a It is recommended that air-speed sensors be aligned in the centre for parallel flow.

b All surround panel thermocouples should be located centrally.

Figure 7 — Location of temperature and air speed sensors

6 Test procedure

6.1 General

The general operating procedure for the hot-box measurements shall follow that specified in ISO 8990, especially the initial performance check given in ISO 8990:1994, 2.9. In addition, the following requirements shall be complied with.

6.2 Calibration measurements

This subclause describes the additional calibration tests which are required for the testing of windows and doors.

6.2.1 General

These tests are required to ensure that suitable test conditions are set up and that the surround panel heat flow and surface heat transfer coefficients can be fully accounted for.

The calibration measurements shall be carried out at a minimum of six densities of heat flow rates which cover the required range of specimen testing.

It is recommended to make the calibration measurements at a minimum of three different mean air temperatures $\theta_{c,me}$ [$\theta_{c,me} = (\theta_{c,i} + \theta_{c,e})/2$] in steps of ± 5 K by varying the cold side air temperature, retaining constant conditions of air movement on the cold side and constant air temperature and natural convection on the warm side. Using this procedure, surface resistances and coefficients of heat transfer can be determined as a function of the total density of heat flow rate through the calibration panel.

NOTE It is considered that for non-homogeneous test specimens, such as windows or doors, the mean heat transfer conditions over the measured area are comparable to those of the given calibration panel.

6.2.2 Total surface resistance

6.2.2.1 Measurement

The first calibration test shall be made with the thin panel ($d_{cal} \approx 20$ mm) at a mean temperature of approximately 10 °C or appropriate to national standards and a temperature difference, $\Delta\theta_c$ between warm and cold sides, of (20 ± 2) K or appropriate to national standards (see Annex A and ISO 8990 for the determination of the environmental temperatures).

The air velocity on the cold side shall be adjusted for the first calibration test by throttling or by fan speed adjustment to give a total surface thermal resistance (warm and cold side) $R_{s,t} = (R_{(s,t),st} \pm 0{,}01)$ m²·K/W, e.g. (0,17 ± 0,01) m²·K/W or as appropriate to national standards. Thereafter, the fan speed settings and the throttling devices shall remain constant for all subsequent calibration measurements. The air velocity setup used for the calibration procedure shall be used for all tests with specimens of windows or doors.

6.2.2.2 Calculation

Calculate the total surface thermal resistance of the warm and cold side, $R_{s,t}$, expressed in m²·K/W, using Equation (1):

$$R_{s,tot} = \frac{\Delta\theta_{n,cal} - \Delta\theta_{s,cal}}{q_{cal}} \quad (1)$$

where

$\Delta\theta_{n,cal}$ is the difference between environmental temperatures on each side of the calibration panel, in kelvin, calculated according to Annex A;

$\Delta\theta_{s,cal}$ is the surface temperature difference of the calibration panel, in kelvin;

q_{cal} is the density of heat flow rate of the calibration panel determined from the known thermal resistance, R_{cal}, of the calibration panel (at the mean temperature, θ_{cal}) and the surface temperature difference, $\Delta\theta_{s,cal}$, calculated using Equation (2):

$$q_{cal} = \frac{\Delta\theta_{s,cal}}{R_{cal}} \quad (2)$$

where R_{cal} is the thermal resistance of the calibration panel at the mean temperature of the panel, calculated using Equation (3):

$$R_{cal} = \sum \frac{d_j}{\lambda_j} \qquad (3)$$

where

d_j is the thickness of layer j, in metres;

λ_j is the thermal conductivity of layer j, in W/(m·K).

The total surface resistance, $R_{s,t}$, shall be plotted as a function of the density of heat flow rate, q_{cal}, of the calibration panel. These characteristics shall be used to determine the total surface resistances of all subsequent measurements of test specimens (windows and doors).

6.2.3 Surface resistances and surface coefficients of heat transfer

6.2.3.1 General

Surface coefficients of heat transfer (convective and radiative parts) are required in order to determine the environmental temperatures (in accordance with the procedures given in Annex A and ISO 8990). Surface temperature measurements on the calibration panel at different densities of heat flow rate allow the determination of the surface coefficients of heat transfer. The surface resistances shall be calculated using Equations (4) and (5):

$$R_{si} = \frac{\theta_{ni,cal} - \theta_{si,cal}}{q_{cal}} \qquad (4)$$

$$R_{se} = \frac{\theta_{se,cal} - \theta_{ne,cal}}{q_{cal}} \qquad (5)$$

where

q_{cal} is the density of heat flow rate through the calibration panel, in W/m^2;

$\theta_{ni,cal}$ is the environmental temperature of the warm side, in degrees Celsius;

$\theta_{si,cal}$ is the warm side surface temperature of the calibration panel, in degrees Celsius;

$\theta_{se,cal}$ is the cold side surface temperature of the calibration panel, in degrees Celsius;

$\theta_{ne,cal}$ is the environmental temperature of the cold side, in degrees Celsius.

6.2.3.2 Convective fraction

Evaluate the radiative and convective parts of the surface coefficients of heat transfer from the calibration data for the warm and cold side in accordance with the procedure given in Annex A and determine the convective fraction, F_c, using Equation (6):

$$F_c = \frac{h_c}{h_c + h_r} \qquad (6)$$

where

h_c is the convective coefficient of heat transfer, in W/(m²·K);

h_r is the radiative coefficient of heat transfer, in W/(m²·K).

The variation of the convective fraction, F_c, shall be plotted for both sides as a function of q_{cal} (density of heat flow rate of the calibration panel). It is intended to be used by interpolation for the determination of the environmental temperatures of all subsequent measurements of test specimens using Equation (7):

$$\theta_n = F_c \theta_c + (1 - F_c)\, \theta_r \tag{7}$$

Annex E gives an analytical calibration procedure as an alternative. From detailed heat balance equations, analytical functions are established for the convective and radiative parts of the density of heat flow rate, q_{cal}. These functions should be used for all subsequent measurements of test specimens (windows and doors).

6.2.4 Surround panel and edge corrections

From the data set of the thicker calibration panel ($d_{cal} \approx 60$ mm), calculate and plot the thermal resistance, R_{sur}, of the surround panel as a function of its mean temperature. Equations (8), (9) and (10) are derived from the heat flows shown in Figure 5:

$$R_{sur} = \frac{A_{sur} \Delta\theta_{s,sur}}{\Phi_{in} - \Phi_{cal} - \Phi_{edge}} \tag{8}$$

where

A_{sur} is the projected area of the surround panel, in square metres;

$\Delta\theta_{s,sur}$ is the difference between the average surface temperatures of the surround panel, in kelvin;

Φ_{in} is the heat input to the metering box appropriately corrected for heat flow through the metering box walls and the flanking losses, in watts (see ISO 8990:1994, 2.9.3.3);

Φ_{cal} is the heat flow rate through the calibration panel, in watts, given by Equation (9):

$$\Phi_{cal} = A_{cal} q_{cal} \tag{9}$$

Φ_{edge} is the heat flow rate through the edge zone between the calibration panel and the surround panel, in watts, given by Equation (10):

$$\Phi_{edge} = L_{edge} \Psi_{edge} \Delta\theta_c \tag{10}$$

where

L_{edge} is the perimeter length between surround panel and specimen, in metres;

Ψ_{edge} is the linear thermal transmittance of the edge zone between surround panel and specimen, in W/(m·K); values for Ψ_{edge} are given in Annex B, Table B.1;

$\Delta\theta_c$ is the difference between the warm and the cold side air temperatures, in kelvin.

This calibration procedure allows the results from a given size of calibration panel to be applied to a different size of test specimen without repeating the whole calibration measurement process.

6.3 Measurement procedure for test specimens

The measurement of the test specimens shall be made under the same conditions as for the corresponding calibrations as described in 6.2.2, at a mean air temperature of approximately 10 °C and an air temperature difference of $\Delta\theta_c \approx (20 \pm 2)$ K, or according to national standards. Areas of condensation or ice formation on the specimen can affect the measured thermal transmittance. Therefore, the relative humidity in the metering chamber shall be kept at low enough levels to avoid that situation.

The density of heat flow rate, q_{sp}, expressed in watts per square metre, through the test specimen during the measurement shall be calculated using Equation (11):

$$q_{sp} = \frac{\Phi_{in} - \Phi_{sur} - \Phi_{edge}}{A_{sp}} \quad (11)$$

where

A_{sp} is the projected area of the test specimen, in square metres;

Φ_{in} is the heat input to the metering box appropriately corrected for heat flow through the metering box walls and the flanking losses, in watts (see ISO 8990:1994, 2.9.3.3);

Φ_{edge} is the edge zone heat flow rate according to Equation (10), in watts; the actual value for Ψ_{edge} shall be taken from Table B.2 or shall be calculated in accordance with ISO 10211;

Φ_{sur} is the heat flow rate through the surround panel in watts, given by Equation (12):

$$\Phi_{sur} = \frac{A_{sur}\Delta\theta_{s,sur}}{R_{sur}} \quad (12)$$

where

A_{sur} is the projected area of the surround panel, in square meters;

$\Delta\theta_{s,sur}$ is the difference between the average surface temperatures of the surround panel, in kelvin;

R_{sur} is the thermal resistance of the surround panel, in $m^2 \cdot K/W$, determined by calibration (see example given in Figure D.1).

The measured overall thermal transmittance, U_m, expressed in $W/(m^2 \cdot K)$, of the test specimen shall be calculated using Equation (13):

$$U_m = \frac{q_{sp}}{\Delta\theta_n} \quad (13)$$

where $\Delta\theta_n$ is the difference between the environmental temperatures on each side of the system under test, in Kelvin [see Equation (7), where F_{ci}, F_{ce} are determined by calibration] (see example given in Figure D.3).

6.4 Expression of results for standardized test applications

The total surface resistance, $R_{s,t}$, in $m^2 \cdot K/W$, corresponding to the measured thermal transmittance, U_m, shall be evaluated from the calibration data as a function of the density of heat flow rate, q (see example given in Figure D.2), derived by interpolation or by an analytical iteration procedure (see Annex E).

The measured thermal transmittance of the specimen, U_m, shall be corrected for the effect of q on the total surface resistance, $R_{s,t}$, to obtain the standardized thermal transmittance, U_{st}, in $W/(m^2 \cdot K)$, using Equation (14):

$$U_{st} = \left[U_m^{-1} - R_{s,tot} + R_{(s,tot),st} \right]^{-1} \quad (14)$$

For windows and doors in Europe, a standardized value $R_{(s,t),st}$ = 0,17 m²·K/W is used.

NOTE For a worked example of a calibration measurement and window test, see Annex D.

7 Test report

The test report shall contain all information required for a test report specified in ISO 8990:1994, 3.7. In addition, the following information shall be given.

a) All details necessary to identify the product tested:

1) the height, width, and thicknesses, including dishing or bowing of the glazing unit under laboratory conditions and immediately after the test;

2) the details of the glazing unit incorporated in the window or door and details of the spacer and frame construction and material, as well as cross-section of the specimen;

3) a sketch showing the structure of the specimen [e.g. position and thickness of glass panes, thickness of gas space(s), type of gas filling, composition of door leaves, position of internal foils, frame composition and geometry, sashes, fittings and any additional sealings of joints];

4) the position relevant to the surround panel.

b) The method of calibration, i.e. summary details of the range of calibrations appropriate to these tests (calibration curves or analytical calibration functions).

c) The results of the following measurements:

1) basic data set of the measurements (see ISO 8990);

2) mean environmental temperature on the warm side, θ_{ni}, in degrees Celsius;

3) mean environmental temperature on the cold side, θ_{ne}, in degrees Celsius;

4) air speed and direction on the warm (when measured) and the cold side, in metres per second;

5) the measured thermal transmittance, U_m, as obtained from the tests;

6) for standardized tests, the thermal transmittance, U_{st}, expressed in W/(m²·K), corrected to the standard total surface resistance, rounded to two significant figures;

7) for product declaration purposes, the following nomenclature is used:

— windows: $U_W = U_{st}$;

— windows with closed shutters or blinds $U_{WS} = U_{st}$;

— doors $U_D = U_{st}$.

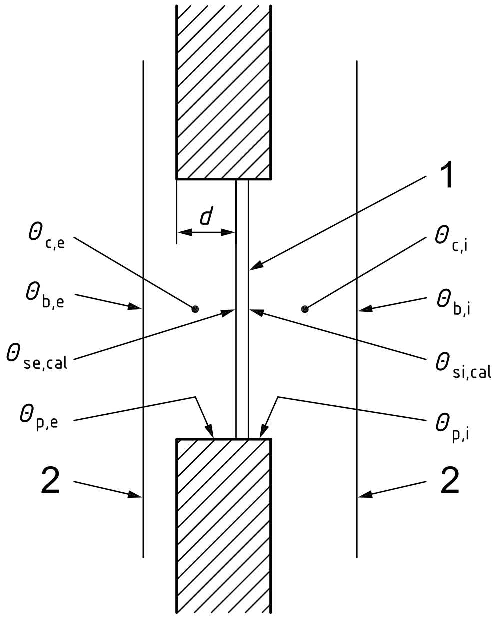
8) estimation of the approximate error of the measurement (e.g. procedure given in Reference [7]).

Annex A
(normative)

Environmental temperatures

A.1 General

In this annex, the notations shown in Figure A.1 are used.



Key

1 calibration panel or test specimen

2 baffle

$\theta_{s,cal}$ average surface temperature of the calibration panel, in degrees Celsius

θ_p average surface temperature of the reveal of surround panel (top, side, bottom), in degrees Celsius

θ_b average surface temperature of the baffle, in degrees Celsius

θ_c average air temperature, in degrees Celsius

Figure A.1 — Notations used for the environmental temperature

A.2 Environmental temperature

The environmental temperature, θ_n, is the weighting of the radiant temperature, θ_r, and the air temperature, θ_c. Calculate the environmental temperature, θ_n, in degrees Celsius, on both sides, using Equation (A.1):

$$\theta_n = \frac{h_c\theta_c + h_r\theta_r}{h_c + h_r} \tag{A.1}$$

where

h is the surface coefficients of heat transfer, in W/(m²·K);

c is an index referring to mean air temperature;

r is an index referring to mean radiant temperature.

The convective fraction, F_c, as explained in 6.2.3.2, shall be calculated from the calibration measurements as a function of the density of heat flow rate, q_{cal} (see example given in Figure D.3).

A.3 Mean radiant temperature

The mean radiant temperature, θ_r, in degrees Celsius, of the surfaces "seen" by the surface of the test specimen (calibration panel or window) shall be calculated using Equations (A.2), (A.3) or (A.4):

a) If the depth of the surround panel reveal $d \leqslant 50$ mm, then Equation (A.2) is used:

$$\theta_r = \theta \tag{A.2}$$

b) If $\left| \theta_b - \theta_p \right| \leqslant 5$ K, then Equation (A.3) is used:

$$\theta_r = \frac{\alpha_{cb}\theta_b + \alpha_{cp}\theta_p}{\alpha_{cb} + \alpha_{cp}} \tag{A.3}$$

c) Otherwise, Equation (A.4) is used:

$$\theta_r = \frac{\alpha_{cb}h_{cb}\theta_b + \alpha_{cp}h_{cp}\theta_p}{\alpha_{cb}h_{cb} + \alpha_{cp}h_{cp}} \tag{A.4}$$

The radiant heat transfer coefficient, h_r, in W/(m²·K), is calculated using Equation (A.5):

$$h_r = \alpha_{cb}h_{cb} + \alpha_{cp}h_{cp} \tag{A.5}$$

where h_{cb}, h_{cp} are the black body radiant heat transfer coefficients calculated using Equations (A.6) and (A.7):

$$h_{cb} = \sigma (T_{cal}^2 + T_b^2)(T_{cal} + T_b) \tag{A.6}$$

$$h_{cp} = \sigma (T_{cal}^2 + T_p^2)(T_{cal} + T_p) \tag{A.7}$$

where

σ is the Stefan-Boltzmann constant; $\sigma = 5{,}67 \times 10^{-8}$ in W/(m²·K⁴);

α_{cb}, α_{cp} are radiation factors from the baffle to the calibration panel and the surround panel reveals to the calibration panel, calculated using Equations (A.8) and (A.9).

The values of h_{cb}, h_{cp} are calculated from the data set of the calibration panel and can be used for all specimens with the appropriate cold-side temperature.

The radiation factors, α_{cb}, α_{cp}, are calculated ignoring second reflections, using Equations (A.8) and (A.9):

$$\alpha_{cb} \approx \varepsilon_{cal}\varepsilon_b \left[f_{cb} + \left(1 - \varepsilon_p\right) f_{cp} f_{pb} \right] \tag{A.8}$$

$$\alpha_{cp} \approx \varepsilon_{cal}\varepsilon_{p}\left[f_{cp} + (1-\varepsilon_{b})f_{cb}f_{bp} + (1-\varepsilon_{p})f_{cp}f_{pp}\right] \tag{A.9}$$

where

f is the view factor between two surfaces;

ε is the hemispherical emissivity.

The following subscripts indicate the direction of radiant heat exchange:

cb is the direction from calibration panel to baffle;

cp is the direction from calibration panel to surround panel reveal;

pb is the direction from surround panel reveal to baffle;

bp is the direction from baffle to surround panel reveal;

pp is the direction from surround panel reveal to surround panel reveal.

View factors depending on the depth of the surround panel reveal, d, for the standardized test aperture are given in Tables A.1 and A.2.

A.4 Convective surface heat transfer coefficient

The convective surface heat transfer coefficient, h_c, shall be calculated for the warm and cold side using Equation (A.10):

$$h_c = \frac{q_{cal} - h_r\left|\theta_r - \theta_{cal}\right|}{\left|\theta_c - \theta_{cal}\right|} \tag{A.10}$$

where q_{cal} is the density of heat flow rate through the calibration panel, in watts per square metre.

Table A.1 — View factors for a 1 230 mm × 1 480 mm aperture

View factor	Reveal depth d				
	0 mm	50 mm	100 mm	150 mm	200 mm
f_{cb}	1,0	0,930	0,867	0,809	0,756
f_{pp}	0,0	0,059	0,103	0,142	0,177
$f_{cp} = f_{bp}$ [a]	0,0	0,070	0,133	0,191	0,244
f_{pb} [b]	0,5	0,471	0,449	0,429	0,412

[a] See Equation (A.11).

[b] See Equation (A.12).

Table A.2 — View factors for a 1 200 mm × 1 200 mm aperture

View factor	Reveal depth d				
	0 mm	50 mm	100 mm	150 mm	200 mm
f_{cb}	1,0	0,922	0,853	0,790	0,733
f_{pp}	0,0	0,068	0,117	0,160	0,198
$f_{cp} = f_{bp}$ [a]	0,0	0,078	0,147	0,210	0,267
f_{pb} [b]	0,5	0,466	0,442	0,420	0,401

[a] See Equation (A.11).

[b] See Equation (A.12).

$$f_{cp} = f_{bp} = 1 - f_{cb} \tag{A.11}$$

$$f_{pb} = \frac{\left(1 - f_{pp}\right)}{2} \tag{A.12}$$

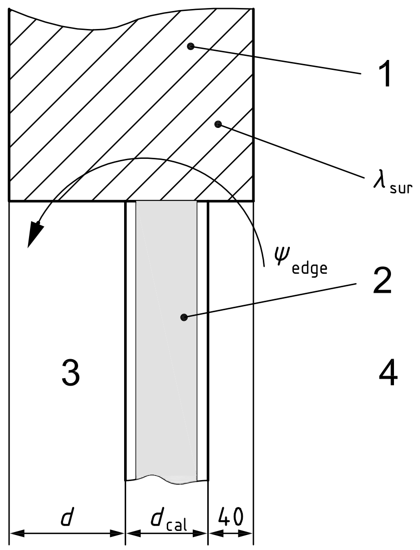
For other geometries, a detailed radiation heat exchange calculation procedure shall be used (see References [8] or [9]).

Annex B
(normative)

Linear thermal transmittance of the edge zone

B.1 For thermal transmittance of the edge zone, see Figures B.1 and B.2 and Table B.1.

Dimensions in millimetres



Key

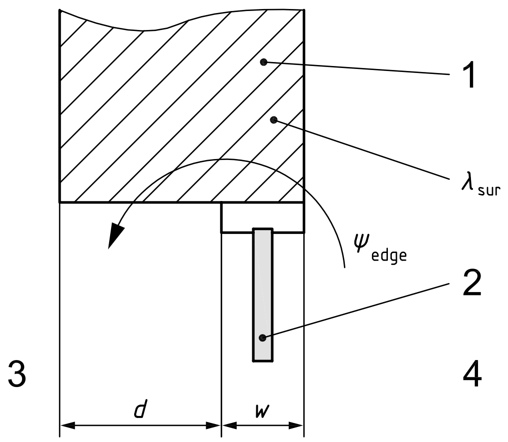
1 surround panel

2 calibration panel

3 cold side

4 warm side

Figure B.1 — Glazed calibration panel with thickness d_{cal}



Key

1 surround panel

2 test specimen

3 cold side

4 warm side

Figure B.2 — Test specimen with frame width w

Table B.1 — Linear thermal transmittance for glazed calibration panel

d	Ψ_{edge} for d_{cal} = 60 mm W/(m·K)			Ψ_{edge} for d_{cal} = 100 mm W/(m·K)		
mm	λ_{sur} 0,030 W/(m·K)	λ_{sur} 0,035 W/(m·K)	λ_{sur} 0,040 W/(m·K)	λ_{sur} 0,030 W/(m·K)	λ_{sur} 0,035 W/(m·K)	λ_{sur} 0,040 W/(m·K)
0	0,004 4	0,005 0	0,005 7	0,002 3	0,002 7	0,003 1
20	0,004 1	0,004 8	0,005 4	0,002 4	0,002 8	0,003 2
40	0,005 0	0,005 8	0,006 5	0,003 0	0,003 5	0,004 0
60	0,006 3	0,007 2	0,008 2	0,003 9	0,004 6	0,005 2
80	0,007 7	0,008 8	0,010 0	0,005 0	0,005 7	0,006 5
100	0,009 0	0,010 4	0,011 8	0,006 0	0,007 0	0,007 9
120	0,010 4	0,012 0	0,013 6	0,007 1	0,008 2	0,009 3
140	0,011 7	0,013 5	0,015 3	0,008 1	0,009 4	0,010 7
160	0,013 0	0,015 0	0,017 0	0,009 1	0,010 6	0,012 0
180	0,014 2	0,016 4	0,018 5	0,010 1	0,011 7	0,013 3
200	0,015 3	0,017 7	0,020 0	0,011 1	0,012 8	0,014 5
Ψ values for intermediate λ_{sur}, d_{cal} and d values are obtained by linear interpolation.						

B.2 For linear thermal transmittance for test specimen, see Table B.2.

Table B.2 — Linear thermal transmittance for test specimen

w mm	d mm	Ψ_{edge} W/(m·K) λ_{sur} 0,030 W/(m·K)	λ_{sur} 0,035 W/(m·K)	λ_{sur} 0,040 W/(m·K)	w mm	d mm	Ψ_{edge} W/(m·K) λ_{sur} 0,030 W/(m·K)	λ_{sur} 0,035 W/(m·K)	λ_{sur} 0,040 W/(m·K)
40	60	0,011 2	0,012 6	0,013 9	100	40	0,002 9	0,003 3	0,003 6
	80	0,014 2	0,016 0	0,017 7		80	0,006 3	0,007 1	0,007 9
	120	0,018 9	0,021 4	0,023 8		120	0,009 3	0,010 6	0,011 8
	160	0,023 0	0,026 2	0,029 2		160	0,012 0	0,013 8	0,015 5
	200	0,026 3	0,029 9	0,033 5		200	0,014 4	0,016 6	0,018 6
50	50	0,007 9	0,008 8	0,009 7	110	40	0,002 6	0,002 9	0,003 2
	80	0,011 9	0,013 5	0,015 0		80	0,005 7	0,006 4	0,007 2
	120	0,016 3	0,018 5	0,020 6		120	0,008 5	0,009 7	0,010 9
	160	0,020 1	0,022 9	0,025 6		160	0,011 1	0,012 7	0,014 3
	200	0,023 2	0,026 5	0,029 7		200	0,013 4	0,015 3	0,017 3
60	40	0,005 3	0,005 9	0,006 5	120	40	0,002 3	0,002 6	0,002 8
	80	0,010 3	0,011 6	0,012 9		80	0,005 1	0,005 8	0,006 5
	120	0,014 4	0,016 4	0,018 3		120	0,007 8	0,008 9	0,010 0
	160	0,017 8	0,020 4	0,022 8		160	0,010 2	0,011 7	0,013 2
	200	0,020 8	0,023 8	0,026 7		200	0,012 4	0,014 3	0,016 1
70	30	0,003 3	0,003 6	0,003 9	130	40	0,002 1	0,002 3	0,002 6
	60	0,006 8	0,007 6	0,008 4		80	0,004 7	0,005 3	0,006 0
	120	0,012 6	0,014 4	0,016 1		120	0,007 2	0,008 2	0,009 2
	160	0,016 0	0,018 3	0,020 5		160	0,009 5	0,010 9	0,012 3
	200	0,018 8	0,021 5	0,024 1		200	0,011 6	0,013 3	0,015 0
80	20	0,001 8	0,002 0	0,002 1	140	40	0,001 9	0,002 1	0,002 3
	40	0,003 8	0,004 3	0,004 7		80	0,004 3	0,004 9	0,005 5
	80	0,007 9	0,008 9	0,009 9		120	0,006 7	0,007 6	0,008 6
	160	0,011 3	0,012 9	0,018 5		160	0,008 9	0,010 2	0,011 4
	200	0,017 1	0,019 6	0,022 0		200	0,010 8	0,012 5	0,014 0
90	10	0,000 8	0,000 9	0,000 9	150	40	0,001 7	0,001 9	0,002 1
	30	0,002 4	0,002 7	0,002 9		80	0,004 0	0,004 5	0,005 0
	60	0,005 2	0,005 9	0,006 5		120	0,006 2	0,007 1	0,007 9
	120	0,010 2	0,011 6	0,013 0		160	0,008 3	0,009 5	0,010 7
	200	0,015 7	0,018 0	0,020 2		200	0,010 2	0,011 7	0,013 2

Ψ values for intermediate values of λ_{sur} can be obtained by linear interpolation.

If $w > 150$ mm, then Ψ_{edge} is very small and may be neglected ($\Psi = 0$).

Annex C
(informative)

Design of calibration transfer standard

C.1 Design of glazed calibration panels

C.1.1 General

For the calibration of the surface resistances and for checking the surround panel thermal resistance, a calibration panel is used which works like a large heat flux transducer. The calibration panel consists of a homogeneous, well-characterized core material made from insulation board, which has a known thermal conductivity, and is covered on both sides with material with known emissivity, e.g. a sheet of normal glass (see Reference [10]).

C.1.2 Materials

C.1.2.1 **Core material**, of white expanded polystyrene (EPS) with a density of approximately 28 kg/m^3.

The core of both panels should be made from the same sheets of EPS from which the thermal conductivity specimens were taken.

C.1.2.2 **Cover material**, of 4 mm-thick toughened float glass with chamfered edges.

C.1.2.3 **Adhesive**, temperature stable down to the calibration temperature of the cold side.[2)]

C.1.3 Construction details

C.1.3.1 Layout of adhesive spots

Glue the glass to the EPS using a suitable adhesive compound in a 4×4 array of glue points for 1,20 m × 1,20 m panels, and a 4×6 array for 1,48 m × 1,23 m panels. Care should be taken that the glue spots do not coincide with the positions of the surface thermocouples that are fixed during the hot-box calibration measurements.

C.1.3.2 Method of applying the adhesive

C.1.3.2.1 Fix the toughened glass to the EPS core material using adhesive silicone compound glue points about 35 mm in diameter. The glue points should be distributed evenly and care should be taken to avoid positions where the surface thermocouples are fixed during the calibration measurements.

C.1.3.2.2 The following method has been shown to be successful in producing an even adhesive “spot” about 35 mm in diameter. Metal “washers” with a 28 mm diameter hole and 0,5 mm thick are placed in the required array on the EPS surface. The holes are filled flush to the top surface with adhesive compound and then the washers are removed.

2) Dow Corning 7091 is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 12567 and does not constitute an endorsement by ISO of this product.

C.1.3.2.3 The glass is put in position, ensuring that the edges are square to the EPS material. The joint is put under pressure by placing a piece of 19-mm thick plywood on top of the glass and weighting with buckets filled with sand. (A weight of 100 kg evenly distributed over the surface has been found to be adequate.)

C.1.3.2.4 It is very important that the glass be thoroughly cleaned using a solvent such as acetone, prior to fixing adhesive.

C.1.3.2.5 Tape the edges of the panels to reduce moisture pick-up and always keep the panels in a dry environment.

C.1.3.3 Determination of panel thickness

The accurate determination of the EPS sheet thickness and the average overall panel thickness is one of the most critical stages in the fabrication of the calibration panels.

Determine the EPS sheet thickness and the average glazed panel thickness as precisely as practicable. An uncertainty of ± 0,1 mm in 12 mm is ± 0,8 % in conductivity.

Measure the panel thickness in at least 25 places, uniformly spread over the panel surface.

For the purpose of calculating the thermal conductivity of the calibration panel, the thickness of the core is assumed to be the average gap between the inner surfaces of the two glass sheets. A correction may be made for the air gap if required.

The thickness of glass is very uniform and may be assumed to be the thickness as measured at the edges.

C.1.3.4 Thermal conductivity measurements

The thermal conductivity of the EPS should be measured with an apparatus conforming to the procedures specified in ISO 8301 and ISO 8302. In any case, the thermal conductivity should be measured to an uncertainty of better than ± 3,6 % at the 95 % confidence level.

C.1.3.5 Method of mounting thermocouples

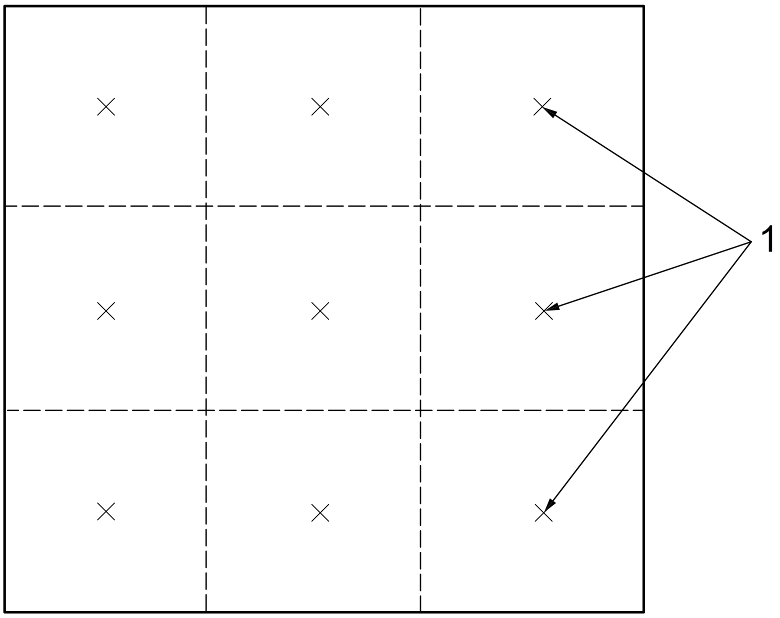
Thermocouples should be made of wire with a maximum diameter of 0,3 mm.

The insulation should be stripped back a minimum of 15 mm from the hot junction.

The thermocouple should be taped to the surface for a minimum of 100 mm.

The tape should be of paper “masking tape” type.

On each side, at least nine temperature sensors should be installed, evenly distributed (see Figure C.1).



Key

1 temperature sensor

NOTE This figure is not to scale.

Figure C.1 — Temperature sensor location on calibration transfer standard

C.2 Calibration transfer standard design

A large heat flux transducer is used in the calibration of the surface heat transfer coefficients (see Reference [4]). The calibration transfer standard (CTS) consists of a homogeneous, well-characterized, core calibration material made from insulation board which has a known thermal conductivity, measured by the test methods given in References [11] or [12]. A recommended CTS core material is 12,7 mm nominal thickness expanded polystyrene (beadboard), having a density in excess of 20 kg/m^3, that has been aged unfaced in the laboratory for a minimum of 90 days. [Expanded polystyrene with a nominal density of 50 kg/m^3 and a nominal thermal conductivity of 0,033 W/(m·K) has been used with success. Machining the surfaces of the expanded polystyrene to ensure flatness is also recommended.]

Suitable facing materials are 3 mm- to 6 mm-thick tempered float glass (glass sheets of thickness 4 mm, with a nominal thermal conductivity of 1 W/(m·K) and a nominal surface hemispherical emittance of 0,84 have been used with success) or 3 mm- to 6 mm-thick clear polycarbonate sheet. [The surface emissivity of the polycarbonate should be precisely measured and used where appropriate in calculations requiring the CTS's surface emissivity. Polycarbonate sheets of thickness 4 mm, with a nominal thermal conductivity of 0,2 W/(m·K) and a nominal surface hemispherical emittance of 0,90 have been used with success.]

Prior to assembly of the CTS, measure the thermal conductivity of the material used for the core of the CTS in a guarded hot plate (see Test Method C 177 in Reference [11]) or a heat flow meter (see Test Method C 518 in Reference [12]) at a minimum of three temperatures over the range of use (–10°C, 0°C, and 10°C are recommended).

The temperature sensors are installed area-weighted. Table C.1 gives the minimum number of temperature sensors per side for a wide range of CTS sizes.

Table C.1 — Temperature sensors

Size of CTS m	Area of CTS m^2	Minimum number of sensors	Recommended number of sensors	Recommended arrays
0,61 × 1,22	0,74	12	18	3 × 6
0,91 × 1,52	1,39	18	24	4 × 6
1,22 × 1,83	2,23	24	32	4 × 8
1,22 × 2,13	2,60	28	42	6 × 7
1,83 × 2,03	3,72	40	48	6 × 8

The temperature sensors should be laid out over equal areas to simplify the area-weighting calculation (that is, the average row, column or overall area-weighted temperature becomes the average temperature of the row, column or total sensors for a side). The temperature sensors should be able to measure accurately the temperature difference across the core material of the CTS. It has been found satisfactory to use 30-gauge (0,3 mm) or smaller diameter copper-constantan insulated thermocouple wire from the same wire lot for both sides of the CTS to obtain an accurate core temperature difference. The wire pair with a smaller diameter should have the insulation stripped off to expose approximately 10 mm of bare wire and then each wire is separately soldered to one side of a thin (0,08 mm nominal thickness) copper shim material approximately 20 mm × 20 mm in size. The constantan wire should be soldered to the centre of the copper shim and the copper thermocouple wire should be separately soldered to the copper shim approximately 6 mm in distance from the constantan-shim solder point. The recommended solder is resin core, lead 60/40, 6 mm nominal diameter, and the resulting solder joints should be cleaned with alcohol to remove excess solder material resin residue. The reverse smooth side of the shim material is then adhered with a thin film of two-part epoxy[3)] to the glazing facing inner surfaces. After the epoxy has dried and all epoxy removed from the surrounding glazing surface, the glazing facing inner surfaces and the expanded polystyrene core material faces are coated with a thin film of a polystyrene[4)] compatible water-based contact adhesive. After allowing the contact adhesive to dry (a minimum of 24 h at room temperature with a relative humidity less than 50 % is recommended; when dry, the contact adhesive does not stick to the touch), the expanded polystyrene is adhered to the glazing facings by applying an ample uniform pressure to the glazing outer faces for an appropriate length of time to allow the glazing faces to permanently bond to the expanded polystyrene.

Since the thermal conductivity of the core material is known (previously measured) and it is possible to accurately measure its thickness, the conductivity of the core material can be calculated. This allows the heat flux through the CTS to be determined from measurement of the temperature difference across the core material.

It is permissible to calculate the surface temperature of the glazed CTS from the glass/core interface temperatures using the known thermal resistance of the glass.

3) Loctite Minute Bond 312 is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 12567 and does not constitute an endorsement by ISO of this product.

4) HB Fuller XR-1377-24-LT-Blue Contact is an example of a suitable product available commercially. This information is given for the convenience of users of this part of ISO 12567 and does not constitute an endorsement by ISO of this product.

Annex D
(informative)

Example of calibration test and measurement of window specimen

D.1 Calibration test with panel size 1,20 m × 1,20 m

Two calibration panels with total thermal resistance approximately 0,4 $m^2 \cdot K/W$ and 1,5 $m^2 \cdot K/W$ and total thickness 20 mm and 59 mm, respectively, were used. The panels were built with core material of expanded polystyrene and covered on both sides with 4 mm float glass according to Annex C (panel dimensions: 1,20 m × 1,20 m). The calibration panel was installed in a surround panel made of polystyrene of thickness 100 mm. The measured data are summarized in Tables D.1 to D.4.

The basic data for the polystyrene core and surround panel material were measured in a hot plate apparatus in accordance with ISO 8302. The measured data are

a) panel 1 ($d = 20$ mm): $R_{cal} = 0{,}408\,405 - 0{,}001\,487\ \theta_{me}$,

b) panel 2 ($d = 59$ mm): $R_{cal} = 1{,}548\,55 - 0{,}004\,88\ \theta_{me}$, and

c) surround panel ($d = 100$ mm): $\lambda_{sur} = 0{,}031\,45 + 0{,}000\,18\ \theta_{me}$,

where θ_{me} is the mean panel temperature in degrees Celsius.

Table D.1 — Calibration panels

Measured value			Panel 1			Panel 2		
d	overall thickness	m	0,020			0,059		
A	area of panel	m^2	1,44			1,44		
A_{sur}	area of surround panel	m^2	1,56			1,56		
A_t	hot-box metering area	m^2	3,00			3,00		
L	perimeter length	m^2	4,80			4,80		
Test number			2	1[a]	3	5	4	6
Cold temperature								
θ_{ce}	(air)	°C	9,86	0,54	– 9,95	9,86	0,58	– 9,98
$\theta_{se,b}$	(baffle)	°C	9,91	0,70	– 9,74	9,84	0,56	– 9,93
$\theta_{se,cal}$	(calibration panel)	°C	10,98	2,73	– 6,77	10,34	1,40	– 8,80
$\theta_{se,p}$	(reveal panel)	°C	10,36	1,58	– 8,48	10,12	1,02	– 9,37
$\theta_{se,sur}$	(surround panel)	°C	10,01	0,95	– 9,35	10,01	0,88	– 9,46
Warm temperature								
θ_{ci}	(air)	°C	19,99	20,93	20,23	19,85	19,89	19,91
$\theta_{si,b}$	(baffle)	°C	19,61	20,24	19,22	19,66	19,55	19,40
$\theta_{si,cal}$	(calibration panel)	°C	17,80	16,66	14,02	19,17	18,51	17,80
$\theta_{si,p}$	(reveal panel)	°C	18,78	18,55	16,82	19,27	18,76	18,20
$\theta_{si,sur}$	(surround panel)	°C	19,62	20,18	19,08	19,50	19,09	18,65
Φ_{in}	(input power)	W	30,43	60,59	87,99	13,84	26,25	39,95
v_i	(air flow warm side, down)	m/s	0,1	0,1	0,1	0,1	0,1	0,1
v_e	(air flow cold side, up)	m/s	1,6	1,6	1,5	1,6	1,5	1,5

[a] Test no.1 was used to fix the fan settings on the cold side.

Table D.2 — Linear thermal transmittance and view factors of the calibration panels

Value resulting from mounting instructions			Remark	Panel 1	Panel 2
Total thickness of the calibration panel		mm	—	20	59
Total thickness of the surround panel		mm	—	100	100
Surround panel reveal depth – warm side		mm	—	40	40
Surround panel reveal depth – cold side		mm	—	40	1
Ψ_{edge} for $\lambda = 0{,}033$ W/(m·K)		W/(m·K)	Table B.1	—	0,004 8
Warm side	view factors	f_{cbi}	Table A.2	0,938	0,938
		f_{ppi}	Table A.2	0,054	0,054
		f_{cpi}	Equation (A.11)	0,062	0,062
		f_{bpi}	Equation (A.11)	0,062	0,062
		f_{pbi}	Equation (A.12)	0,473	0,473
	radiant factors	α_{cbi}	Equation (A.8)	0,750	0,750
		α_{cpi}	Equation (A.9)	0,050	0,050
Cold side	view factors	f_{cbe}	Table A.2	0,938	0,998
		f_{ppe}	Table A.2	0,054	0,001
		f_{cpe}	Equation (A.11)	0,062	0,002
		f_{bpe}	Equation (A.11)	0,062	0,002
		f_{pbe}	Equation (A.12)	0,473	0,500
	radiant factors	α_{cbe}	Equation (A.8)	0,750	0,797
		α_{cpe}	Equation (A.9)	0,050	0,002
NOTE The radiant factors have been calculated with the following emissivities: $\varepsilon_{cal} = 0{,}84$; $\varepsilon_p = 0{,}92$; $\varepsilon_b = 0{,}95$.					

Table D.3 — Calculation of surround panel thermal resistance, R_{sur}

Data element		Remark	Panel 2 (59 mm)		
$\Delta\theta_c$	K	—	9,99	19,31	29,89
$\Delta\theta_{s,sur}$	K	—	9,49	18,21	28,11
$\theta_{me,sur}$	°C	—	14,76	9,98	4,61
Φ_{in}	W	—	13,84	26,25	39,95
Φ_{cal}	W	Equation (9)	8,61	16,43	25,09
Φ_{edge}	W	Equation (10)	0,23	0,44	0,69
$\Phi_{in} - \Phi_{cal} - \Phi_{edge}$	W	—	5,00	9,38	14,17
R_{sur}	m²·K/W	Equation (8)	**2,961**	**3,029**	**3,095**
Optional check with data of hot plate measurement					
$\theta_{me,sur}$	°C	—	14,76	9,98	4,61
λ_{sur}	W/(m·K)	linear regression	0,034 1	0,033 3	0,032 3
R_{sur}	m²·K/W	d/λ_{sur}	2,933	3,003	3,096
$\Delta R_{sur}/R_{sur}$	%	relative difference	– 1,0	– 0,9	– 0,0

Table D.4 — Calculation of surface resistances and convective fraction, F_c

Data element		Remark	Panel 1 (20 mm)			Panel 2 (59 mm)		
$\theta_{me,cal}$	°C	—	14,39	9,70	3,63	14,75	9,96	4,50
$\Delta\theta_{s,cal}$	K	—	6,82	13,93	20,79	8,83	17,11	26,60
R_{cal}	$m^2 \cdot K/W$	Equation (3)	0,387	0,394	0,403	1,477	1,499	1,527
q_{cal}	W/m^2	Equation (2)	17,62	35,36	51,59	5,98	11,41	17,42
$h_{cb,i}$	$W/(m^2 \cdot K)$	Equation (A.6)	5,64	5,62	5,52	5,68	5,66	5,63
$h_{cb,e}$	$W/(m^2 \cdot K)$	Equation (A.6)	5,17	4,71	4,22	5,15	4,67	4,16
$h_{cp,i}$	$W/(m^2 \cdot K)$	Equation (A.7)	5,61	5,58	5,45	5,67	5,63	5,60
$h_{cp,e}$	$W/(m^2 \cdot K)$	Equation (A.7)	5,19	4,73	4,25	5,16	4,68	4,18
$h_{r,i}$	$W/(m^2 \cdot K)$	Equation (A.5)	4,51	4,50	4,42	4,55	4,53	4,51
$h_{r,e}$	$W/(m^2 \cdot K)$	Equation (A.5)	4,14	3,77	3,38	4,11	3,73	3,32
$\theta_{r,i}$	°C	Equation (A.3)	19,56	20,13	19,07	19,64	19,50	19,32
$\theta_{r,e}$	°C	Equation (A.2)	9,94	0,76	– 9,66	9,84	0,56	– 9,93
$h_{c,i}$	$W/(m^2 \cdot K)$	Equation (A.10)	4,42	4,62	4,72	5,68	5,02	5,00
$h_{c,e}$	$W/(m^2 \cdot K)$	Equation (A.10)	11,88	12,74	13,15	8,17	10,10	11,58
$F_{c,i}$	—	Equation (6)	0,495	0,506	0,516	0,555	0,526	0,526
$F_{c,e}$	—	Equation (6)	0,741	0,772	0,796	0,665	0,730	0,777
$\theta_{ni,cal}$	°C	Equation (7)	19,77	20,54	19,67	19,75	19,71	19,63
$\theta_{ne,cal}$	°C	Equation (7)	9,88	0,59	– 9,89	9,85	0,57	– 9,97
$\Delta\theta_{n,cal}$	K	—	9,89	19,95	29,56	9,90	19,13	29,60
R_{si}	$m^2 \cdot K/W$	Equation (4)	0,112	0,110	0,110	0,098	0,105	0,105
R_{se}	$m^2 \cdot K/W$	Equation (5)	0,062	0,061	0,060	0,081	0,072	0,067
$R_{s,t}$	$m^2 \cdot K/W$	Equation (1)	**0,174**	**0,171**	**0,170**	**0,179**	**0,177**	**0,172**

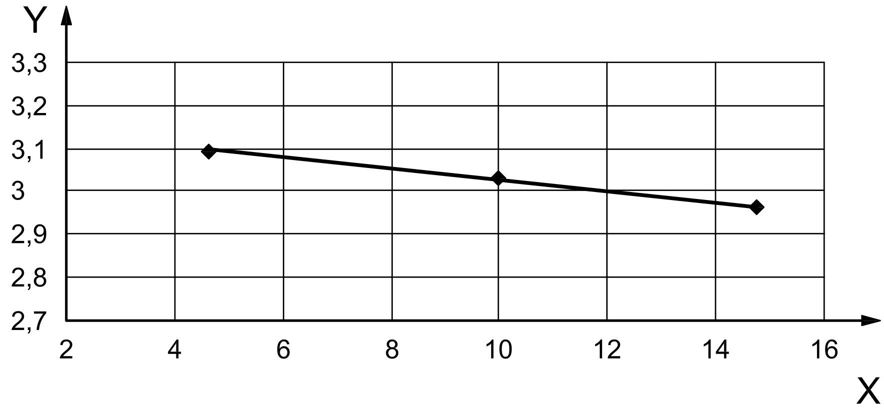
The results from the calibration measurements are plotted in Figures D.1, D.2 and D.3. The following regression curves have been derived by least-square fits from the data set:

a) thermal resistance of the surround panel: $R_{sur} = 3{,}157 - 0{,}013\,2\ \theta_{me,sur}$

b) convective fraction: $F_{c,i} = 0{,}534\,3 - 0{,}000\,6\ q_{sp}$

$F_{c,e} = 0{,}696\,2 + 0{,}002\,2\ q_{sp}$

c) total surface resistance: $R_{s,t} = 0{,}186\,9\ q_{sp}^{(-0{,}025)}$

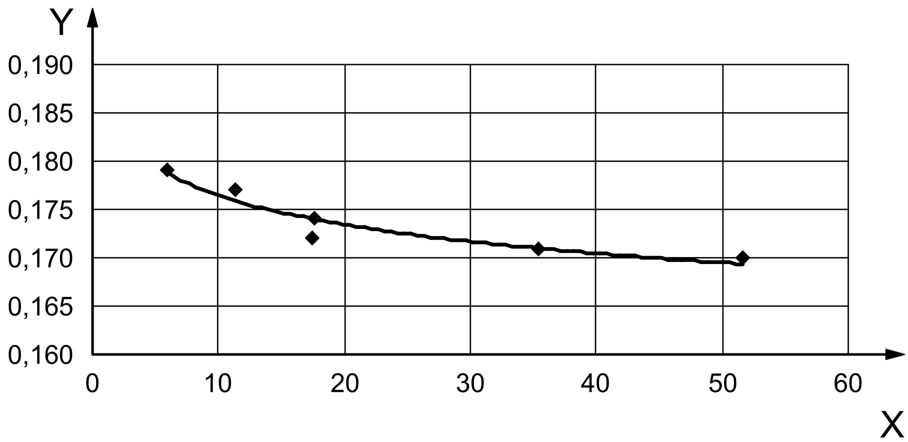


Key

X surround panel mean temperature, °C

Y R_{sur}, m^2 K/W

Figure D.1 — Thermal resistance of the surround panel, R_{sur}

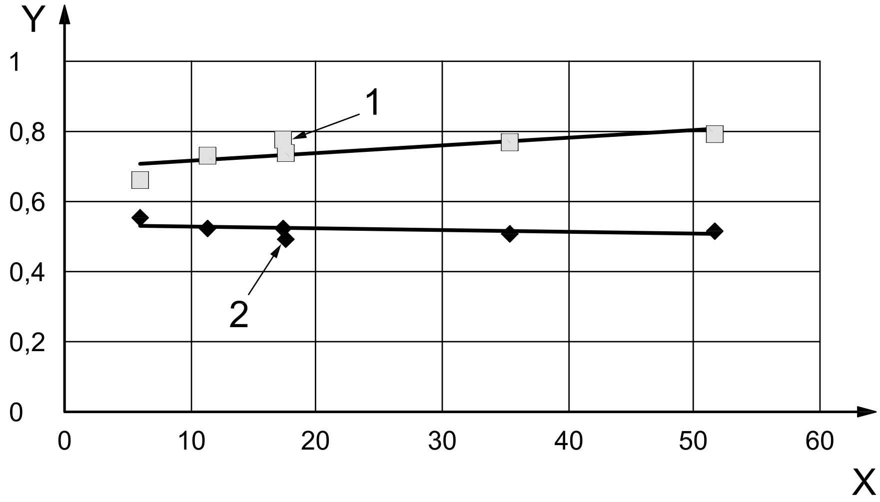


Key

X density of heat flow rate, q, W/m^2

Y $R_{s,t}$, m^2 K/W

Figure D.2 — Total surface resistance, $R_{s,t}$



Key

X density of heat flow rate, q, W/m^2

Y convective fraction, F_c

1 warm side

2 cold side

NOTE The curves have been derived by least-square fits.

Figure D.3 — Convective fraction, F_c

D.2 Window specimen measurement

General data of the tested window are as follows (see Tables D.5 to D.7).

a) Type: PVC window divided into three parts, with the right-hand side fully fixed glazed, left-hand side divided into two parts: above, small top-hung casement with opening to the outside; below, single side-hung casement with opening restriction (see Figure D.4).

b) Frame:

— three-chamber PVC frame with steel reinforcement in the mullion only;

— frame thickness 68 mm.

c) Glazing: 2 IGUs (insulating glass units) (4 mm × 16 mm × 4 mm) with low-e coating on position 3 (type K, $\varepsilon \approx 0{,}16$) and air filling.

d) Dimensions:

— window height 1,480 m;

— window width 1,230 m;

— projected window area (1,230 m × 1,480 m) = 1,820 m^2;

— glass area [1,368 m × 0,514 m + 0,438 m (0,902 m + 0,222 m)] = 1,195 m^2;

— projected frame area 0,625 m^2;

— heat exchange area of the frame 0,726 m^2;

— total heat exchange area of the window 1,921 m^2;

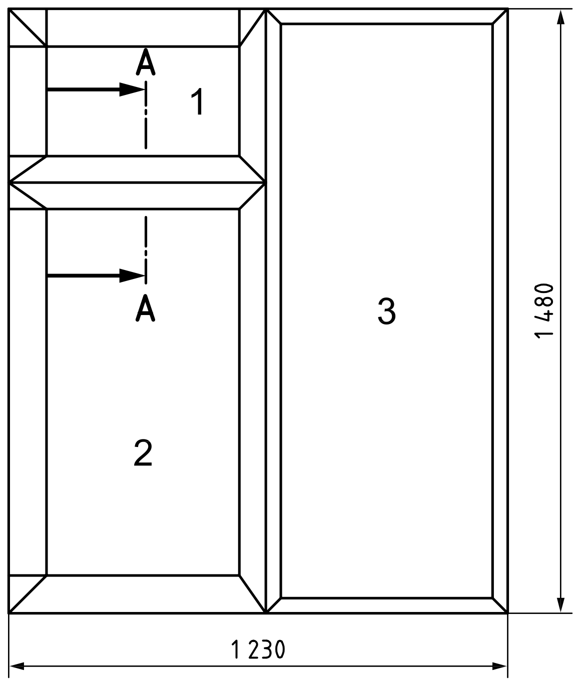
— ratio total heat exchange to projected window area 1,055.

e) Seals:

— in the sash: two hollow section seals circulating, turned around in the corners;

— at the glass: on both sides, silicone sealant.

Dimensions in millimetres



Key

1 top-hung casement with opening to the side

2 side-hung casement with opening restriction

3 fully fixed glazed section

Figure D.4 — View of window

Dimensions in millimetres

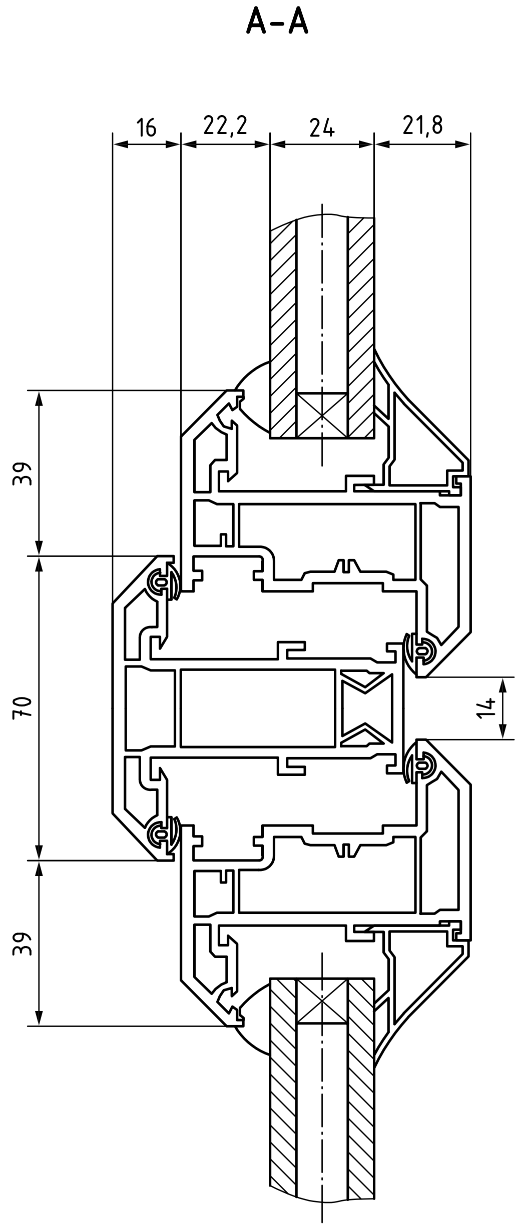


Figure D.5 — Details, vertical section A-A

Table D.5 — Window data

Data element			Value
w	frame width	m	0,068
d_{sur}	surround panel thickness	m	0,100
A_{sp}	area of window	m^2	1,820
A_{sur}	area of surround panel	m^2	1,180
L	perimeter length	m	5,42

Table D.6 — Window measurement results

Data element			Value
Cold temperature (measured)			
θ_{ce}	(air)	°C	0,53
$\theta_{se,b}$	(baffle)	°C	0,68
$\theta_{se,p}$	(reveal)	°C	0,74
$\theta_{se,sur}$	(surround panel)	°C	0,82
Warm temperature (measured)			
θ_{ci}	(air)	°C	21,57
$\theta_{si,b}$	(baffle)	°C	20,75
$\theta_{si,sur}$	(surround panel)	°C	20,66
Φ_{in}	(input power in hot box)	W	78,68
v_i	(air flow warm, down)	m/s	0,10
v_e	(air flow cold, up)	m/s	1,90

Table D.7 — Calculation of the thermal transmittance of the window

Data element			Value	Remarks
$\theta_{me,sur}$	(mean temp. of surround panel)	°C	10,74	—
R_{sur}	(surround panel resistance)	$m^2 \cdot K/W$	3,015	Figure D.1/regression
λ_{sur}	(conductivity of surround panel)	W/(m·K)	0,033	—
Ψ_{edge}	for $w = 68$ mm/$d = 32$ mm	W/(m·K)	0,003 5	Table B.2
$\Delta\theta_{s,sur}$	(temp., difference of surround panel)	K	19,84	—
$\Delta\theta_c$	(air temp. difference)	K	21,04	—
Φ_{in}	(input power in hot box)	W	78,68	—
Φ_{sur}	(surround panel heat flow)	W	7,76	Equation (12)
Φ_{edge}	(edge zone heat flow)	W	0,40	Equation (10)
q_{sp}	(heat flow density of specimen)	W/m^2	38,75	Equation (11)
F_{ci}	(convective fraction – warm)	—	0,511	Figure D.3/regression
F_{ce}	(convective fraction – cold)	—	0,781	Figure D.3/regression
$R_{s,t}$	(total surface resistance)	$m^2 \cdot K/W$	0,171	Figure D.2/regression
θ_{ri}	(radiant temp. – warm)	°C	20,75	Equation (A.2)
θ_{re}	(radiant temp. – cold)	°C	0,68	Equation (A.2)
θ_{ni}	(environmental temp. – hot)	°C	21,17	Equation (7)
θ_{ne}	(environmental temp. – cold)	°C	0,56	Equation (7)
$\Delta\theta_n$	(environmental temp. difference)	K	20,61	—
U_m	(measured)	$W/(m^2 \cdot K)$	1,88	Equation (13)
ΔU_m	(uncertainty of the measurement)	$W/(m^2 \cdot K)$	± 0,08	Annex F
$R_{(s,t),st}$		$(m^2 \cdot K)/W$	0,17	European value
U_{st}	(standardized)	$W/(m^2 \cdot K)$	1,90	Equation (14)
U_W	(window U-value)	$W/(m^2 \cdot K)$	1,90	

Annex E
(informative)

Analytical calibration procedure using heat balance equations

E.1 General

The heat flow density through the calibration panel may be expressed by the surface heat balance equations on each side of the panel.

E.2 Warm-side surface

$$q_{\text{cal}} = q_{\text{ri,cal}} + q_{\text{ci,cal}} \tag{E.1}$$

$$q_{\text{ri,cal}} = h_{\text{ri}} \left(\theta_{\text{bi}} - \theta_{\text{si,cal}} \right) \tag{E.2}$$

$$F_{1\text{b}} = 1 \Bigg/ \left[\frac{1}{\varepsilon_{\text{cal}}} + \frac{A_{\text{cal}}}{A_{\text{b}}} \left(\frac{1}{\varepsilon_{\text{b}}} - 1 \right) \right] \tag{E.3}$$

For calibration panels, which are installed flush with the surround panel, the approximation given by Equation (E.4) may be used:

$$q_{\text{ri,cal}} = \sigma F_{1\text{b}} \left(T_{\text{bi}}^4 - T_{\text{si,cal}}^4 \right) \tag{E.4}$$

The convective heat flux may be determined by the approach given as Equations (E.5) and (E.6):

$$q_{\text{ci,cal}} = h_{\text{ci}} \left(\theta_{\text{ci}} - \theta_{\text{si,cal}} \right) \tag{E.5}$$

$$h_{\text{ci}} = K \left(\theta_{\text{ci}} - \theta_{\text{si,cal}} \right)^{B-1} \tag{E.6}$$

The coefficients K and B are determined from the calibration tests.

The density of heat flow rate, q_{cal}, may be determined using Equation (E.7):

$$q_{\text{cal}} = \frac{\Delta \theta_{\text{s,cal}}}{R_{\text{cal}}} \tag{E.7}$$

where R_{cal} is the thermal resistance of the calibration panel from laboratory tests as a function of the mean temperature, in $m^2 \cdot K/W$.

E.3 Cold-side surface

$$q_{\text{cal}} = q_{\text{re,cal}} + q_{\text{ce,cal}} \tag{E.8}$$

When the baffle and the air temperature are close together (± 0,5 K), a combined heat transfer coefficient, h_e, may be used:

$$h_e = \frac{q_{cal}}{\left(\theta_{se,cal} - \theta_{ce}\right)} \tag{E.9}$$

Otherwise, the same procedure should apply as for the warm-side heat balance.

E.4 Calibration results

The following information should be given as results of the calibration tests:

a) h_e, the combined surface heat transfer coefficient on the cold side, in W/(m²·K);

b) F_{1b}, the overall interchange factor for radiation on the warm side;

c) K and B, the coefficients for convective heat transfer on the warm side.

The values from the calibration test should be used for all window test measurements, using the heat balance Equations (E.10) to (E.12):

$$q_{ri} = \sigma F_{1b}\left(T_{bi}^4 - T_{si,sp}^4\right) \tag{E.10}$$

$$q_{ci} = K\left(\theta_{ci} - \theta_{si,sp}\right)^B \tag{E.11}$$

$$q_{ri} + q_{ci} = q_m \tag{E.12}$$

where q_m is the density of heat flow rate measured by the calorimeter, in watts per square metre.

This set of equations should be solved for the unknown surface temperature, $\theta_{si,sp}$, by iteration.

The cold-side surface temperature, $\theta_{se,sp}$, may be determined using Equation (E.13):

$$\theta_{se,sp} = \frac{q_m}{h_e} + \theta_{ce} \tag{E.13}$$

For more details, see References [6] and [7].

Annex F
(informative)

Uncertainty analysis for hot boxes

F.1 General

The accuracy of the thermal transmittance (U-value, U-factor) of a test specimen (wall, roof, floor, window, door, etc.) measured in a building assembly thermal test facility (hot box) depends upon the test apparatus, test conditions, operating procedure and the specimen properties. By conducting an uncertainty analysis of a specific thermal test facility, the measurement uncertainty can be identified and quantified. The estimation procedure for the uncertainty associated with the U-value result for a thermal test facility should be established and reported along with the measured U-values of fenestration products. Improvements in the U-value uncertainty can be achieved by reducing the individual uncertainties associated with the various elements of the overall uncertainty for the hot-box test apparatus studied.

F.2 Introduction of uncertainty analysis

Uncertainty analysis, as defined by Kline and McClintock[13] and Airy[14], refers to the process of estimating the effect of uncertainties in individual measurements on the final calculated experimental result. An excellent primer on uncertainty and confidence in measurements is UKAS M3003[15].

Due to economic and time constraints, in many engineering experiments it is not practical to statistically estimate the overall measurement uncertainty. Experiments in which the uncertainty is not found by repetition are called single-sample experiments. Several engineering experimentation textbooks (e.g. References [16], [17] and [18]) present the basic methods of uncertainty analysis and discuss their importance in planning, evaluating and reporting experiments. Moffat[19][20][21] explores many aspects of the techniques of single-sample uncertainty analysis. A general discussion on uncertainty analysis applied to thermal test facilities (hot boxes) is given in Yuan[22].

According to Moffat[20] and Kline and McClintock[13], the value of a variable is specified by giving the mean of the readings and an uncertainty interval at a particular confidence level. The uncertainty propagation from variables to result may be analysed by the method of the second power equation presented by Kline and McClintock[13]. Moffat[20] refers to this technique as the Root-sum-square (RSS) method. Using the RSS method (sometimes called “quadrature addition”), the propagation of uncertainty can be analysed for a specific measurement facility and test procedure. Large element uncertainties in any of the measured variables result in large uncertainties of the final calculated result. Therefore, a reduction in a larger element uncertainty is far more important than the same percent reduction in a smaller element uncertainty. Thus, uncertainty analysis is a useful tool in the selection of thermal test facility (hot box) instrumentation.

Uncertainty analysis of thermal tests for fenestration systems have been carried out by Klems[23], Harrison and Dubrous[24], Elmahdy[25], Nussbaumer[26] and Yuan, Russell and Goss[27] who presented methods for determining the uncertainty of U-value measurements for their specific thermal test facilities. Van Dijk[28] developed a spread-sheet for determining the uncertainty based on measurements made using ISO 8990 for "an idealized situation: the uncertainty when measuring a homogeneous specimen".

This annex presents detailed analysis procedures for the estimation of the uncertainty of hot-box tests using ASTM C1363 and ASTM C1199 and this part of ISO 12567 and ISO 12567-2 building assembly thermal transmittance test methods. The uncertainty analysis procedures presented in this annex apply to all chamber designs (guarded, calibrated or hybrid). The only difference is in the magnitude of the uncertainty elements and the instruments utilized to make the fundamental measurements.

F.3 Measured U-value uncertainty presentation

The measurement of the thermal transmittance or U-value of a fenestration system in a hot-box test yields a single numerical value; however, equally as important as the U-value value are the uncertainty and the confidence level of the measurement. Therefore, the proper way to express the measured U-value is given as Equation (F.1):

$$U_{\text{sp}} = \bar{U}_{\text{sp}} \pm \Delta^{P} U_{\text{sp}} \tag{F.1}$$

where

$\bar{U}_{\text{sp}}$ is the best estimate for a test specimen's U-value;

$\Delta^{P} U_{\text{sp}}$ is the uncertainty at a specified level, P (e.g. $P = 95$ %).

NOTE The confidence level is P%.

Taken together, these three quantities indicate that there is a P % probability that the true U-value value lies within the ($\bar{U}_{\text{sp}} \pm \Delta^{P} U_{\text{sp}}$) range. The uncertainty and the confidence level are closely related, the larger the level (e.g. 99 %) the larger the resulting uncertainty. The method used to quantify $\Delta^{P} U_{\text{sp}}$ in Equation (F.1) is called uncertainty analysis.

The uncertainty or $\Delta^{P} U_{\text{sp}}$ term in Equation (F.1) can be estimated for a given test apparatus (hot box) and test procedure, and the general procedure for doing this should be developed before any measurement is carried out. Doing so indicates the critical aspects of the measurement procedure and the limitations of the particular test apparatus being used. Since the design and instrumentation used in a specific hot box are usually unique, the uncertainties associated with each element in the specific test apparatus are different from other test apparatuses. The general uncertainty analysis procedure, however, is similar for all hot-box designs and instrumentation.

In the fenestration test methods of this part of ISO 12567, ISO 12567-2 or ASTM C 1199, the test specimen thermal transmittance, U_{sp}, is the fundamental measured result from the thermal test using the hot box. In order to compare test results with other U-value results, such as computer calculated thermal transmittance values, the results should be standardized. In such a procedure, more measured values such as the specimen's total surface heat transfer coefficients (ASTM C 1199), or the specimen's total surface thermal resistances (this part of ISO 12567, ISO 12567-2) have to be obtained and used to calculate a standardized U-value, U_{st}. At the time of publication of this part of ISO 12567, there is no standardization method that correctly reproduces the actual thermal performance of the fenestration product. The additional measured values introduced by the standardization procedure can significantly increase the uncertainty of the U_{st} result in comparison with the uncertainty of the more fundamental U_{sp} result. It is important to improve the current computer models to use variable local heat transfer coefficients on the warm and cold side test specimen surfaces and in the glazing cavity to more accurately model the hot-box conditions. This would allow future calculated U-values to be directly compared with the actual measured thermal transmittance, U_{sp}, instead of the two U_{st} values defined in ASTM C 1199 or the modified U_{st} value from this part of ISO 12567 or ISO 12567-2. This direct validation would permit the computer models to be more reliably used over a wider range of fenestration heat transfer conditions. Therefore, this annex focuses on the investigation of uncertainty elements and their propagation to the basic test results (i.e. the thermal transmittance of the test specimen or U_{sp} value).

A detailed investigation of the uncertainty elements associated with the temperature measurement, power measurement, calibration procedure and material properties are given in this annex. The (RSS) method is used to determine the propagation of uncertainty elements to the measured U-value results. Particular attention is given to the techniques and equations used to evaluate the various heat transfer terms in the total energy balance of the test apparatus.

F.4 Uncertainties of fundamental measurements

The individual uncertainty associated with a fundamental measurement is referred to as an element of uncertainty. Each measurement element of uncertainty combines with other uncertainties to increase the uncertainty of the fundamental measurement. Before considering the uncertainty propagation to the U-value results, the uncertainty of the elements associated with a specific hot-box test apparatus should be investigated.

For a particular hot box, the uncertainty elements can be obtained by either specifications supplied by the manufacturer or the calibration results using calibration data traceable to some national standards. The uncertainty element associated with the measurement of length, temperature, temperature difference, power and thermal conductivity are listed in Table F.1. These uncertainty elements are characteristics of a particular hot box, as illustrated in F.5.

Table F.1 — Uncertainty elements

Uncertainty element	Symbol	Unit
Length	$\Delta^P d$	m
Temperature	$\Delta^P \theta$	°C
Temperature difference	$\Delta^P \delta\theta$	°C
Voltage	$\Delta^P V$	mV
Power	$\Delta^P \Phi_{\text{IN}}$	W
Thermal conductivity	$\Delta^P \lambda$	W/(m·K)

F.5 Uncertainty propagation on the U-value

Each of the uncertainty elements listed in Table F.1 is incorporated into the total uncertainty of the U-value, U_{sp}. The uncertainty propagation is based on the RSS method as described by Kline and McClintock[13]. If a result, R, is based on quantities x_i (i = 1, 2, …, N), as given in the expression below:

$$R = R(x_i), \quad i = 1, 2, ..., N, \; i = 1, 2, \ldots, N$$

where x_i are known with uncertainties $\Delta^P x_i$, each with the same confidence level, P (e.g. P = 95 %):

$$x_i = \bar{x}_i \pm \Delta^P x_i \qquad \text{(confidence level } P\%\text{)}$$

Then, the uncertainty in the computed result, R, is given by Equation (F.2 a):

$$\Delta R = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial R}{\partial x_i} \Delta^P x_i \right)^2} \tag{F.2 a}$$

or by Equation (F.2 b), in percent, of R:

$$\frac{\Delta R}{R} = \sqrt{\sum_{i=1}^{N} \left(\frac{\partial R}{\partial x_i} \frac{\Delta^P x_i}{R} \right)^2} \tag{F.2 b}$$

Using this methodology, the uncertainties for some intermediate elements and for the final U-value can be obtained.

Using a hot-box method (ISO 8990, this part of ISO 12567, ISO 12567-2, ASTM C 1199 or ASTM C1363), the U-value of a specimen can be obtained by Equation (F.3):

$$U_{sp} = \frac{\Phi_{sp}}{A_{sp} \cdot \delta\theta_{ie}} \tag{F.3}$$

where $\delta\theta_{ie} \equiv \theta_i - \theta_e$. Using the RSS method, $\Delta^P U_{sp}/U_{sp}$ can be obtained:

$$\frac{\Delta^P U_{sp}}{U_{sp}} = \sqrt{\left(\frac{\Delta^P \Phi_{sp}}{\Phi_{sp}}\right)^2 + \left(\frac{\Delta^P A_{sp}}{A_{sp}}\right)^2 + \left(\frac{\Delta^P \delta\theta_{ie}}{\delta\theta_{ie}}\right)^2} \tag{F.4}$$

Using Equation (F.4), one can estimate the uncertainty of the U-value with respect to its estimated experimental value. In this equation, the uncertainty element of the temperature difference, $\Delta^P \delta\theta_{ie}$ is listed in Table F.1. Since this is an uncertainty element, no further analysis of it is required. In F.6 and F.7, the uncertainty equations for the calculation of the uncertainty of $\Delta^P A_{sp}$ and $\Delta^P \theta_{sp}$ are presented.

F.6 Uncertainty propagation on the specimen area

The projected area of a test specimen, A_{sp}, can be calculated from the measured width and height measurements using Equation (F.5):

$$A_{sp} = H_{sp} \times w_{sp} \tag{F.5}$$

Using the RSS method, $\Delta^P A_{sp}/A_{sp}$ is given by Equation (F.6):

$$\frac{\Delta^P A_{sp}}{A_{sp}} = \sqrt{\left(\frac{\Delta^P H_{sp}}{H_{sp}}\right)^2 + \left(\frac{\Delta^P w_{sp}}{w_{sp}}\right)^2} \tag{F.6}$$

F.7 Uncertainty propagation on the specimen net heat transfer

F.7.1 General

All of the above analysis applies to ISO 8990, this part of ISO 12567, ISO 12567-2, ASTM C 1199 and ASTM C 1363 hot-box test procedures. However, the methodology for determining the value and uncertainty in the test specimen heat transfer rate, Φ_{sp}, differs for the basic hot box (ISO 8990 and ASTM C 1363) test methods and the fenestration hot box (this part of ISO 12567, ISO 12567-2 or ASTM C 1199) test methods. This is due to the various calibrated heat transfer rates that have to be subtracted from the basic heat transfer in, Φ_{IN}, measurement. In this subclause, the uncertainty of the measured specimen heat transfer rate, Φ_{sp}, for a hot box following either the fenestration test methods of ASTM C 1199, this part of ISO 12567 or ISO 12567-2 is developed. In addition, the uncertainty of the surround panel heat transfer rate, Φ_{sur}, and the test specimen flanking heat transfer rate, $\Phi_{FL,sp}$, should also be determined.

The net heat transfer through a test specimen is obtained by an energy balance on the metering chamber shown in Figure F.1. The result is given by Equation (F.7):

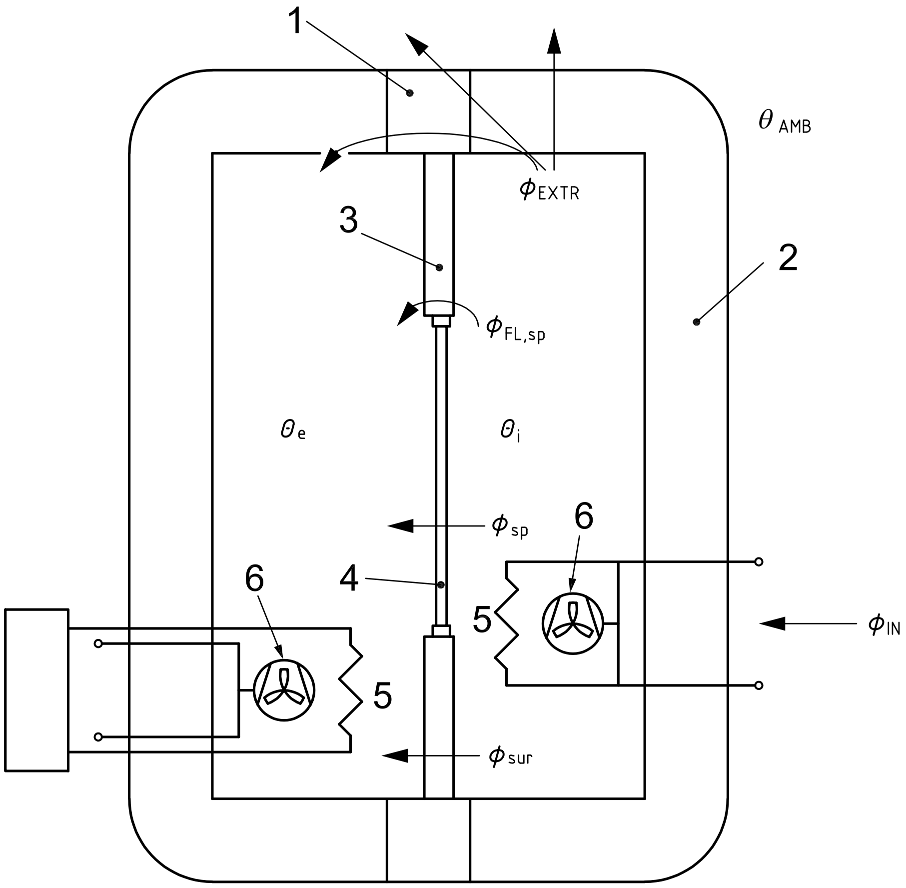
$$\Phi_{sp} = \Phi_{IN} - \Phi_{sur} - \Phi_{EXTR} - \Phi_{FL,sp} \tag{F.7}$$

Equation (F.7) includes the specimen flanking heat transfer and, therefore, it is applicable to specimens with thickness less than that of the surround panel in the hot box. For a specimen with a thickness the same as or slightly larger than that of the surround panel, the last term, $\Phi_{FL,sp}$, should be dropped from Equation (F.7).

Using the RSS method, the uncertainty of the net heat transfer $\Delta^P \Phi_{sp} / \Phi_{sp}$ through the specimen is:

$$\frac{\Delta^P \Phi sp}{\Phi sp} = \sqrt{\left(\frac{\Delta^P \Phi_{IN}}{\Phi_{sp}}\right)^2 + \left(\frac{\Delta^P \Phi sur}{\Phi_{sp}}\right)^2 + \left(\frac{\Delta^P Q_{EXTR}}{Q_{sp}}\right)^2 + \left(\frac{\Delta^P \Phi_{FL,sp}}{\Phi_{sp}}\right)^2} \tag{F.8}$$

Equation (F.8) can be used to calculate the percentage of the uncertainty of the net heat transfer through the specimen once the uncertainty of each of the four terms inside the square root sign are known. The uncertainty of the power input to the metering box, $\Delta \Phi_{IN}$, can be obtained from the elemental uncertainty value as presented in Table F.1. For the remaining three terms, additional analysis should be conducted.



Key

1	surround panel frame	ϕ_{EXTR}	metering chamber extraneous heat transfer
2	metering chamber wall	$\phi_{FL,sp}$	test specimen flanking heat transfer
3	surround panel	ϕ_{IN}	power input
4	test specimen or calibration panel	ϕ_{sp}	heat transfer through the test specimen
5	heating coils	ϕ_{sur}	heat transfer through the surround panel
6	fan	θ_e	cold side (climactic chamber) external air temperature
7	refrigeration system	θ_i	warm side (metering room) internal air temperature
		θ_{AMB}	external ambient temperature

Figure F.1 — Schematic setup for the hot-box metering chamber energy balance

F.7.2 Surround panel heat transfer

The ideal one-dimensional heat transfer through the projected area of the surround panel can be calculated using Equation (F.9) as follows:

$$\Phi_{\text{sur}} = \lambda_{\text{sur}} \left(\frac{A_{\text{sur}}}{d_{\text{sur}}} \right) \times \delta\theta_{\text{sur}} \quad \text{(F.9)}$$

Using the RSS method, the uncertainty for $\Delta^P \Phi_{\text{sur}}$ can be shown to be:

$$\frac{\Delta^P \Phi_{\text{sur}}}{\Phi_{\text{sp}}} = \left(\frac{\Phi_{\text{sur}}}{\Phi_{\text{sp}}} \right) \left(\frac{\Delta^P \Phi_{\text{sur}}}{\Phi_{\text{sur}}} \right) \quad \text{(F.10 a)}$$

where

$$\left(\frac{\Delta^P \Phi_{\text{sur}}}{\Phi_{\text{sur}}} \right) = \sqrt{\left(\frac{\Delta^P \lambda_{\text{sur}}}{\lambda_{\text{sur}}} \right)^2 + \left(\frac{\Delta^P A_{\text{sur}}}{A_{\text{sur}}} \right)^2 + \left(\frac{\Delta^P d_{\text{sur}}}{d_{\text{sur}}} \right)^2 + \left(\frac{\Delta^P \delta\theta_{\text{sur}}}{\delta\theta_{\text{sur}}} \right)^2} \quad \text{(F.10 b)}$$

Using Equation (F.10) together with the results of uncertainty element analysis, as indicated in Table F.1, the uncertainty associated with the heat transfer through the surround panel can be determined. This result is then used in Equation (F.8) for the uncertainty estimate of the net heat transfer through the test specimen.

F.7.3 Extraneous heat transfer

The extraneous heat transfer from the hot-box metering chamber during the test of a specimen includes the metering chamber wall heat transfer to the ambient room, the heat transfer from the metering to climatic chambers through the surround panel frame (called surround panel flanking heat transfer in ASTM C 1199), and any other unwanted heat transfer as shown schematically in Figure F.1. This extraneous heat transfer, Q_{EXTR}, should be accounted for by using an empirical correlation obtained through separate calibration experiments. In the calibration procedure, a homogeneous surround panel (with no test specimen) is mounted in the surround panel frame of the hot box shown in Figure F.1. The calibration experiments are performed using either this part of ISO 12567 and ISO 12567-2 or ASTM C 1199. In these calibration experiments, since there is no test specimen installed, the test specimen net heat transfer, Φ_{sp}, and the test specimen flanking heat transfer, $\Phi_{\text{FL,sp}}$, which appear in Equation (F.7), are both zero. For this situation, solving for extraneous heat transfer in Equation (F.7), gives the following results:

$$\Phi_{\text{EXTR}} = \Phi_{\text{IN}} - \Phi_{\text{sur}} \quad \text{(F.11)}$$

After setting the ambient and metering chamber air temperatures at different levels, the metering wall thermopile temperature difference voltage, the surround panel average temperature difference and the power input are measured. The resulting calibration equation can be obtained by analysing the calibration data using least squares multiple regression.

$$\Phi_{\text{EXTR,ASTM}} = A\delta\theta_{\text{sur}} + BV - C \quad \text{(F.12)}$$

where A, B and C are least square multiple regression curve fitting constants.

For a given $\delta\theta_{\text{sur}}$, which is related to $\delta\theta_{\text{ie}}$, the thermopile temperature difference voltage contribution should be minimized by making the hot-box external ambient temperature, θ_{AMB}, as close to the metering chamber air temperature, θ_{i}, as possible.

F.7.4 Flanking heat transfer

The specimen flanking heat transfer, $\Phi_{\text{FL,sp}}$, can also be determined by calibration by mounting several calibration panels, with different thicknesses and the known thermal properties, in an opening in the surround panel. This specimen flanking heat transfer for a given thickness surround panel can be obtained by Equation (F.13):

$$\Phi_{\text{FL,sp}} = \Phi_{\text{IN}} - \Phi_{\text{sur}} - \Phi_{\text{EXTR}} \tag{F.13}$$

where, Φ_{sur} is be obtained using Equation (F.9) and Φ_{EXTR} is obtained from calibration Equation (F.12).

This part of ISO 12567 contains tables of idealized calculated $\Phi_{\text{FL,sp}}$ values. Calibrated $\Phi_{\text{FL,sp}}$ values are used in this annex because they include the characteristics of a specific hot-box design. In addition, in ASTM C 1199, $\Phi_{\text{FL,sp}}$ values are not required. This is a problem since the previously mentioned two-dimensional fenestration heat transfer calculation programmes with which ASTM C 1199 results are often compared, assuming that $\Phi_{\text{FL,sp}}$ is zero, which might or might not be true for a particular hot-box test.

The sample standard deviation for each of these two calibrated heat transfer rates, Φ_{EXTR} and $\Phi_{\text{FL,sp}}$, is determined not only by the measurement errors, but also by the imperfect structure of the correlation formula chosen to describe the dependence. Therefore, each least-squares fit with its precision interval is:

$$y = y_{\text{c}} \pm t_{\text{v,P}} s_{\text{y}} \tag{F.14}$$

NOTE Confidence level P%

where, y is either Φ_{EXTR} or $\Phi_{\text{FL,sp}}$, y_{c} is the value of y calculated using Equations (F.12) or (F.13) for Φ_{EXTR} and $\Phi_{\text{FL,sp}}$; $t_{\text{v,P}}$ is the t value of the v's degree of freedom and P's confidence level (e.g. $P = 95$ %); s_{y} is the standard deviation of the least-square curve fit y value as described in Neter et al[32]. Additional calibration measurements for Φ_{EXTR} and $\Phi_{\text{FL,sp}}$ can be necessary in order to reduce their uncertainty.

By substituting the appropriate uncertainty values of $\Delta^P \Phi_{\text{EXTR}}$, and $\Delta^P \Phi_{\text{FL,sp}}$ into Equation (F.8), $\Delta^P \Phi_{\text{sp}}/\Phi_{\text{sp}}$ can be calculated. Finally, using Equation (F.4), the uncertainty value for $\Delta^P U_{\text{sp}}/U_{\text{sp}}$ can be estimated.

F.8 Conclusions and recommendations

General uncertainty analysis procedures for the hot-box measurement of the thermal transmittance of both homogeneous test specimens using ISO 8990 or ASTM C 1363 and fenestration test specimens using ASTM C 1199, this part of ISO 12567 or ISO 12567-2 are presented in this annex. After all fundamental uncertainties associated with basic or direct measurements, such as temperature, power and dimensions are known, the RSS method is used extensively in the uncertainty propagation analysis. Also, specific statistical error analysis of calibration procedures is conducted in order to complete this propagation analysis.

An example calculation of the overall uncertainty of a CTS is presented in this annex. The overall uncertainty result is 5,8 % of the measured test specimen U-value. As shown in Table F.4, the largest elemental uncertainty is the specimen flanking loss of 9,1 %.

The metering chamber extraneous heat transfer calibration is an important element in the net heat transfer through the test specimen. Its value has a significant effect on the measurement of the net test specimen heat transfer. It should be minimized by maintaining low metering chamber wall temperature thermopile voltage values. More importantly, the uncertainty associated with its calibration procedure should be minimized as well. At least nine calibration experiments are required to achieve reasonable accuracy as shown in Yuan[22]. Since the calibration correlation equations for this extraneous heat transfer are obtained using regression methods, a corresponding statistical error analysis technique should also be used. Additional calibrations for the extraneous heat transfer and specimen flanking heat transfer are recommended to reduce the overall uncertainty of the specimen U-value.

In order to fully account for all of the heat transfer that does not occur directly through the test specimen, the specimen flanking heat transfer should be subtracted from the total heat input to the metering chamber. The fenestration test method in this part of ISO 12567 requires this calculation, while ASTM C 1199 does not. When this correction is made, the measured U_{sp} value, rather than one of the larger uncertainty standardized U_{st} values, can be shown (see Yuan[22]) to be of the order of 1 % of the numerically calculated U-value for thermally well designed relatively non-projecting fenestration products. It is recommended that changes be made in ASTM C 1199 to include the subtracting out of the test specimen flanking heat transfer. Since the specimen flanking heat transfer in a hot-box measurement is a relatively small quantity, care should be taken during the associated calibration experiments. To achieve accurate U-value measurements, the uncertainty of the specimen flanking heat transfer calibration should be kept below 5 %. It is further recommended that idealized numerically calculated specimen flanking heat transfer results, such as those given in the tables in this part of ISO 12567, only be used when reliable specimen flanking heat transfer physical calibration measurement results do not exist.

F.9 Example determination of uncertainty

F.9.1 Uncertainty of fundamental measurements

The individual uncertainty associated with a fundamental measurement is referred to as an element of uncertainty. Each measurement element of uncertainty combines with other uncertainties to increase the uncertainty of the fundamental measurement. Before considering the uncertainty propagation to the U-value results, the uncertainty of the elements associated with a specific hot-box test apparatus should be investigated.

The uncertainty elements can be obtained by either specifications supplied by the manufacturer or the calibration results using calibration data traceable to some national or International Standards. The uncertainty associated with the measurement of length, temperature, temperature difference, power and thermal conductivity measurements for this example are listed in Table F.2.

In Table F.2, the uncertainties in length, temperature and power were obtained directly from the suppliers of the tape measure, the 30-gauge Type T thermocouple wire and the watt/watthour transducer[30]. The thermocouples used for measuring temperature differences were from the same manufacturer's lot. The uncertainty value was obtained from calibration results for the temperature difference measurement in the hot box as given in Gatland[30]. The thermal conductivity of materials and the associated uncertainty should be obtained using either a guarded hot plate apparatus (ASTM C 177, ISO 8302) or a heat flow meter apparatus (ISO 8301, ASTM C 518).

After setting the ambient and metering chamber air temperatures at different levels, the metering wall thermopile temperature difference voltage, the surround panel average temperature difference and the power input are measured. The results can then be analysed using least squares multiple regression.

Using the ASTM C 1199 test method, the empirical calibration correlation for the extraneous heat transfer, $\Phi_{EXTR,ASTM}$, was obtained using a least squares multiple regression technique as shown in Yuan[22]. The result for nine calibration experiments is:

$$\Phi_{EXTR,ASTM} = 0{,}939\,1\,\delta\theta_{sur} + 1{,}331\;9V - 0{,}482\,7 \qquad (F.12)$$

Similarly, following the test method in this part of ISO 12567, the empirical calibration correlation for the extraneous heat transfer, $\Phi_{EXTR,ISO}$, was obtained as shown in Yuan[22]. The result for nine calibration experiments is:

$$\Phi_{EXTR,ISO} = 0{,}926\,9\;\delta\theta_{sur} + 1{,}266\,7V - 0{,}506\,8 \qquad (F.13)$$

Table F.2 — Uncertainty elements

Uncertainty element	Symbol	Unit	Uncertainty at $P = 95$ %
Length	$\Delta^P d$	M	±0,000 5
Temperature	$\Delta^P \theta$	°C	±0,5
Temperature difference	$\Delta^P \delta\theta$	°C	±0,05
Voltage	$\Delta^P V$	mV	±1,0 %
Power	$\Delta^P \Phi_{IN}$	W	$\pm(0{,}09\ \% \cdot \Phi_{IN} + 0{,}125)$
Thermal conductivity	$\Delta^P \lambda$	W/(m·K)	±1 % [a]
NOTE Uncertainty in guarded hot plate (ASTM C 177) measurements.			
[a] Use 2% to 3% for heat flow meter (ISO 8301 or ASTM C 518) measurements.			

For a given $\delta\theta_{sur}$, which is related to $\delta\theta_{ie}$, the thermopile temperature difference voltage contribution should be minimized by making the hot-box external ambient temperature, θ_{AMB}, as close to the metering chamber air temperature, θ_i, as possible.

The specimen flanking heat transfer, $\Phi_{FL,sp}$, can be determined by calibration by mounting several calibration panels, with different thicknesses and the same known thermal properties, in the surround panel. This flanking heat transfer for a given thickness surround panel can be obtained by Equation (F.14):

$$\Phi_{FL,sp} = \Phi_{IN} - \Phi_{sur} - \Phi_{EXTR} \tag{F.14}$$

where, Φ_{sur} can be obtained using Equation (F.9) and Φ_{EXTR} is obtained from calibration [i.e. Equation (F.12) for ASTM C 1199 conditions and Equation (F.13) for conditions of this part of ISO 12567].

For a given thickness of the surround panel, $\Phi_{FL,sp}$ is a function of the thickness of the specimen, and the least-squares regression fit correlation procedure for the ASTM C 1199 fenestration test method is given in Yuan[22] and Yuan et al[27]. The result for the 102,2 mm surround panel used is:

$$\Phi_{FL,sp;ASTM} = 40{,}798 - 0{,}847\,5 d_{sp} + 0{,}004\,4 d\mathrm{sp}^2 \cdots (0 < d_{sp} < 102{,}2\ \mathrm{mm}) \tag{F.15}$$

where, d_{sp} is the thickness of the specimen in millimetres.

The least-square regression curve fit correlation for the fenestration test method of this part of ISO 12567 is given in Yuan[22] and Yuan et al[27]. The result for the same surround panel is:

$$\Phi_{FL,sp;ISO} = 38{,}974 - 0{,}756\,6 d_{sp} + 0{,}003\,7 d_{sp}^2 \cdots (0 < d_{sp} < 102{,}2\ \mathrm{mm}) \tag{F.16}$$

The difference between Equations (F.15) and (F.16) are due to the different metering and climatic temperatures used in ASTM C 1199 and this part of ISO 12567.

F.9.2 Results of a CTS measurement of uncertainty analysis

A CTS was used to calibrate the specimen surface heat transfer coefficients for fenestration hot-box tests. The plastic (polycarbonate) faced CTS was constructed in accordance with ASTM C 1199 and this part of ISO 12567. Table F.3 shows the summary of the measurement results using ASTM C 1199. More detailed calibration data and results are presented in Yuan[22]. Using the uncertainty data and uncertainty analysis procedures described in this annex, the U-value uncertainty of the CTS and the intermediate calculation results were obtained and are given in Tables F.3 and F.4.

Table F.3 — Measured values and estimated uncertainties at the $P = 95$ % — Confidence level for a plastic-faced CTS calibration panel

Quantity	Symbol	Unit	Measured value	Uncertainty based on Table F.2
Specimen height	H_{sp}	m	1.219	0,000 5
Specimen width	w_{sp}	m	0,609	0,000 5
Specimen thickness	d_{sp}	m	0,021	0,000 5
Hot side air temperature	θ_i	°C	20,99	0,5
Cold side air temperature	θ_e	°C	–17,89	0,5
Surround panel conductivity	λ_{sur}	W/m·K	0,032	0,000 32
Surround panel outer height	H_{sur}	m	2,44	0,000 5
Surround panel outer width	w_{sur}	m	2,44	0,000 5
Surround panel hot side surface temperature	$\theta_{sur,1}$	°C	19,16	0,5
Surround panel cold side surface temperature	$\theta_{sur,2}$	°C	–17,41	0,5
Metering chamber wall thermopile voltage	V	mV	7,41	0,07
Hot side power input	Φ_{IN}	W	168,55	0,277

From Table F.4, the U-value and its uncertainty for this CTS at the $P = 95$ % confidence level is:

$$U_{CTS,ASTM} = 1{,}598 \pm 0{,}093\ W/(m^2 \cdot K) \quad (F.18)$$

NOTE $P = 95$ %.

This represents an estimated 5,8 % uncertainty in the rounded-off measured U-value value of 1,6 W/(m^2·K).

Table F.4 — Calculated values of intermediate quantities and the U-value for the CTS

Quantity	Symbol	Unit	Calculated value	Calculated uncertainty	Percent uncertainty
Specimen projected area	A_{sp}	m^2	0,744	0,0007	0,09 %
Surround panel projected area	A_{sur}	m^2	5,203	0,0010	0,04 %
Extraneous heat transfer	Φ_{EXTR}	W	43,74	1,756	3,8 %
Surround panel heat transfer	Φ_{sur}	W	57,46	0,580	1,0 %
Specimen flanking heat transfer	$\Phi_{FL,sp}$	W	21,16	1,924	9,1 %
Specimen heat transfer	Φ_{sp}	W	46,19	2,683	5,8 %
Specimen U-value	U_{sp}	W/m^2·K	1,598	0,093	5,8 %

For comparison purposes, the ASTM C 177 (surface to surface) resistance of the CTS expanded polystyrene core was combined with the two polycarbonate face resistances and the standardized cold and warm side surface heat transfer resistances to give a predicted CTS U-value of 1,595 W/(m^2·K). This value is within the experimental uncertainty range [1,505 to 1,691 W/(m^2·K)] given in Equation (F.18) and is only 0,16 % from the measured value.

Among the three uncertainty elements of Equation (F.4), the uncertainty of the specimen heat transfer, $\Delta\Phi_{sp}$, as shown in Table F.4, dominated the U-value uncertainty. The uncertainty of $\Delta\Phi_{sp}$ is mainly influenced by the uncertainties of $\Delta\Phi_{FL,sp}$ and $\Delta\Phi_{EXTR}$. These two quantities were calculated using statistical techniques described previously and based on a limited number of calibration experiments. Therefore, in order to decrease the overall U-value uncertainty, additional calibrations for the extraneous heat transfer and additional thickness calibration panels for the specimen flanking heat transfer are necessary.

For examples of fenestration product uncertainty analysis and results for an IEA round-robin insulated glazing unit (IGU) and an ISO round-robin PVC window testing, see Yuan[22].

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