INTERNATIONAL STANDARD

ISO 12567-1

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Thermal performance of windows and doors — Determination of thermal transmittance by 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

Reference number
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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 3.

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 International Standard may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights.

International Standard ISO 12567-1 was prepared by Technical Committee ISO/TC 163, *Thermal insulation*, Subcommittee SC 1, *Test and measurement methods*.

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

— *Part 1: Complete windows and doors*

— *Part 2: Roof windows and other projecting windows*

Annexes A and B are a normative part of this International Standard. Annexes C, D and E are for information only.

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 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. This includes all effects of frames, sashes, shutters, door leaves and fittings.

It does not include:

— 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;

— roof windows and projecting products, where the glass layer projects beyond the cold side roof surface.

NOTE For roof windows and projecting units, the procedure given in ISO 12567-2 (under preparation, see Bibliography [4]) should be used.

Annex A gives methods for the calculation of environmental temperatures.

2 Normative references

The following normative documents contain provisions which, through reference in this text, constitute provisions of this part of ISO 12567. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this part of ISO 12567 are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies. Members of ISO and IEC maintain registers of currently valid International Standards.

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*.

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

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

3 Terms, definitions and symbols

3.1 Terms and definitions

For the purposes of this part of ISO 12567 the terms and definitions given in ISO 7345, ISO 8990 and ISO 9288 apply.

3.2 Symbols

For the purposes of this part of ISO 12567 the 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	$W/(m^2·K)$
H	height	m
L	perimeter length	m
q	density of heat flow rate	W/m^2
R	thermal resistance	$m^2·K/W$
T	thermodynamic temperature	K
U	thermal transmittance	$W/(m^2·K)$
w	width	m
α	radiant factor	—
ΔT, $\Delta\theta$	temperature difference	K
ε	total hemispherical emissivity	—
θ	Celsius temperature	°C
λ	thermal conductivity	W/(m·K)
σ	Stefan-Boltzmann constant	$W/(m^2·K^4)$
Φ	heat flow rate	W
Ψ	linear thermal transmittance	W/(m·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
sp	specimen
st	standardized
sur	surround panel
t	total

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. First, 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 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 and 2).

The principal heat flows through the surround panel and the calibration panel (or test specimen) are shown in Figure 3. 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.

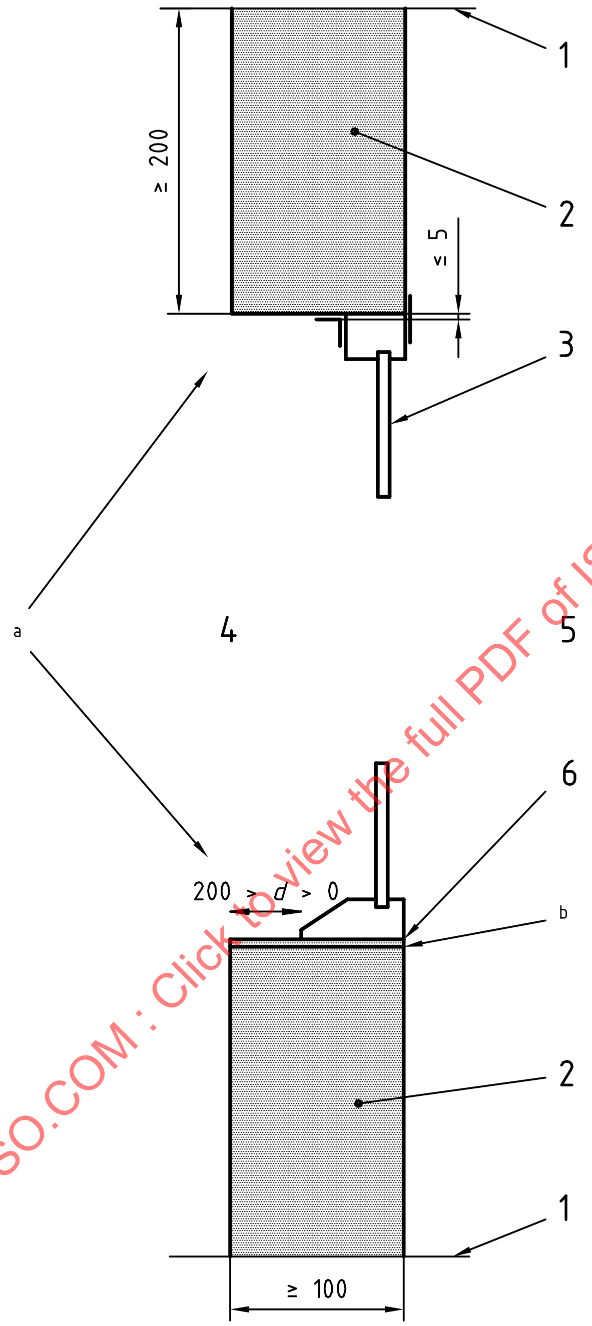
The procedure in this part of ISO 12567 includes a correction for the boundary edge heat flow, so that standardized and reproducible thermal transmittance properties are obtained.

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.

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

Measures 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

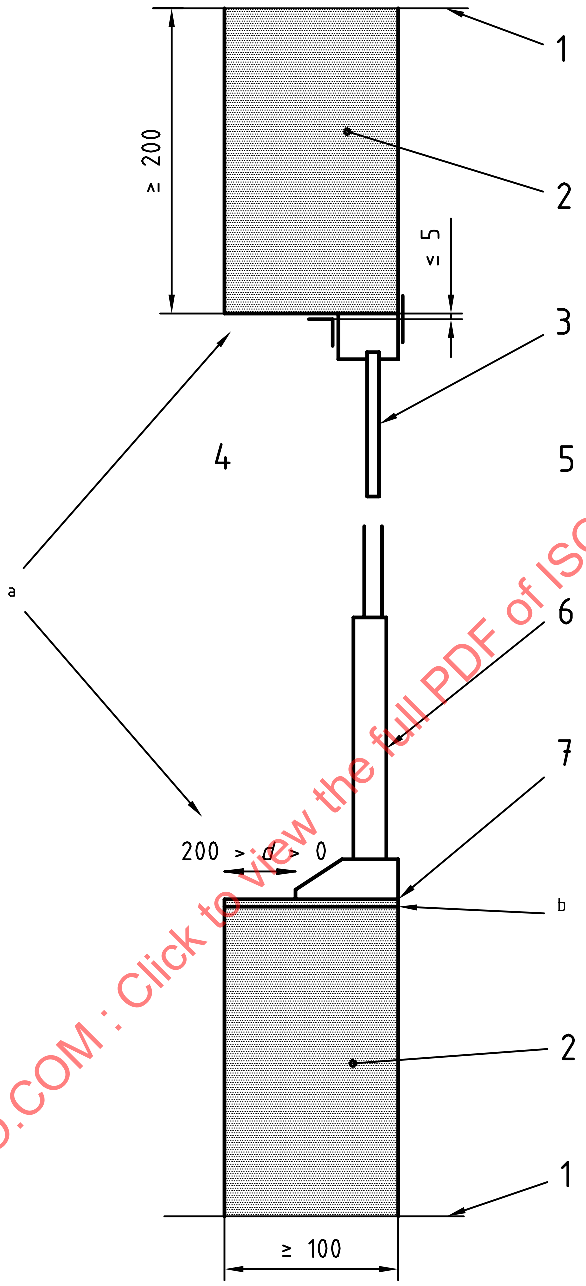
6 Flush sill

a Recommended to be centrally located.

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

Figure 1 — Window system in surround panel

Dimensions in millimetres



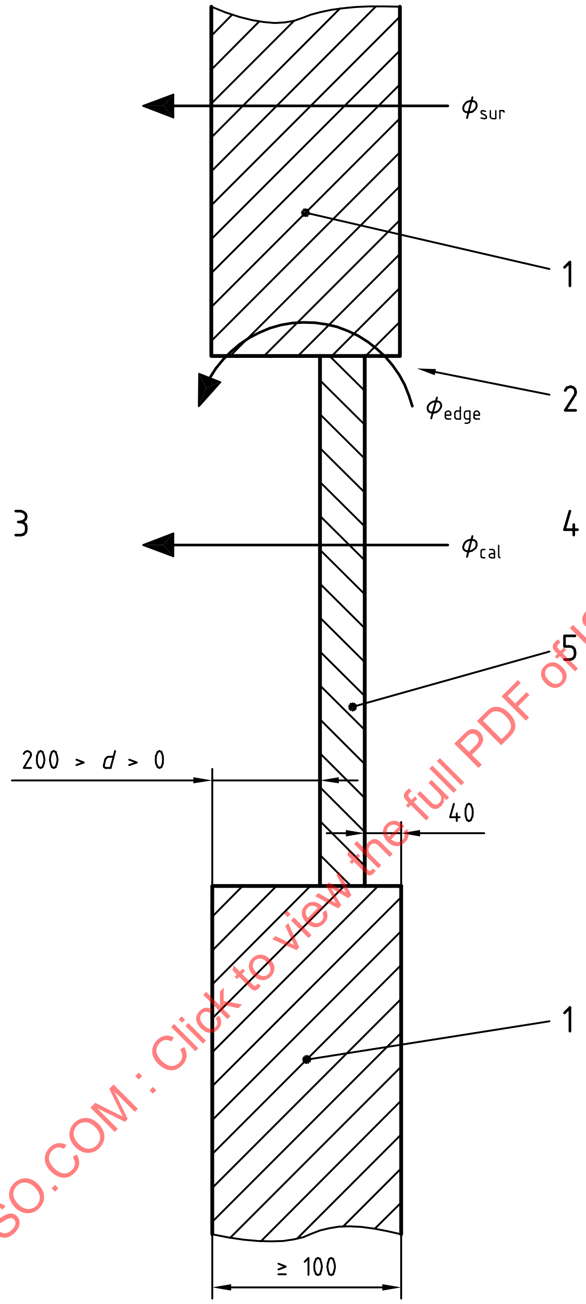
The total gap width between the top and bottom of the specimen and the surround panel aperture shall not exceed 5 mm. It shall be sealed with non-metallic tape or mastic material. The total gap width on both sides between the specimen and the surround panel aperture shall not exceed 5 mm.

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 Recommended to be centrally located.
b Use fill material with same thermal properties as surround panel core.

Figure 2 — Door system in surround panel



Key

1 Surround panel
2 Boundary effect
3 Cold side
4 Warm side
5 Calibration panel

Figure 3 — 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, it is necessary to mount it in a suitable surround panel and deduce the heat flow through it by subtracting that through the surround panel from the total heat input. Also, the test element and the surround panel will usually be of different thickness, so that there will be disturbance of heat flow paths and temperatures in the region of the boundary between the two. The test shall be carried out so 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

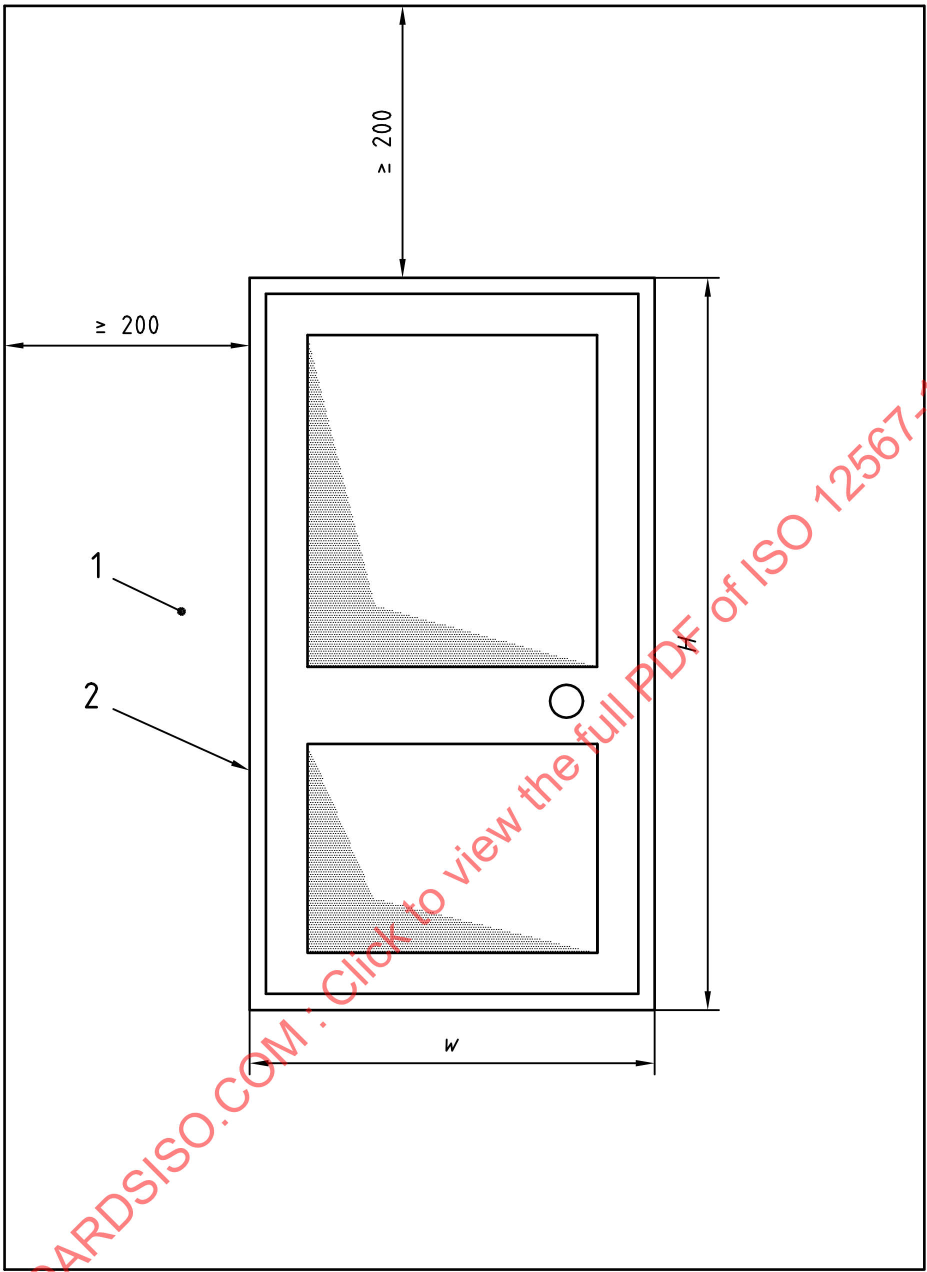
For general applications, specimen sizes may be typical of those found in practice. To ensure consistency of measurement, the specimen should be located as follows. The window or door system shall fill the surround panel aperture. The internal frame face shall be as close to the face of the surround panel as possible, but no part shall project beyond the surround panel faces on either the cold or warm sides, except for handles, rails or fittings which normally project (see Figures 1 and 2).

It is recommended that the aperture should be placed centrally into the surround panel and at least 200 mm from the inside surfaces of the cold and hot boxes to avoid or limit edge heat flow corrections related to the perimeter of the surround panel.

For standardized test applications, the overall sizes recommended are indicated in Table 3, or they shall conform with 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 4 — Surround panel with test specimen

Table 3 — Specimen sizes

Component	**Height** mm	**Width** mm
Window	1480[a]	1230[a]
Door (leaf or doorset)	2000	1000

[a] Standardized specimen size for sound insulation measurements (ISO 140-1 and ISO 140-3).

5.4 Calibration panels

Calibration panels shall be of a size similar to the test specimen (within ± 40 % in height and width). 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 according to 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 by using a guarded hot plate or heat flow meter apparatus in accordance with ISO 8302 or ISO 8301 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 9 positions at the centre of a rectangular grid of equal areas shall be used on the calibration panel and 8 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) according to IEC 60584-1 made from wire with diameter not greater than 0,5 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, 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.

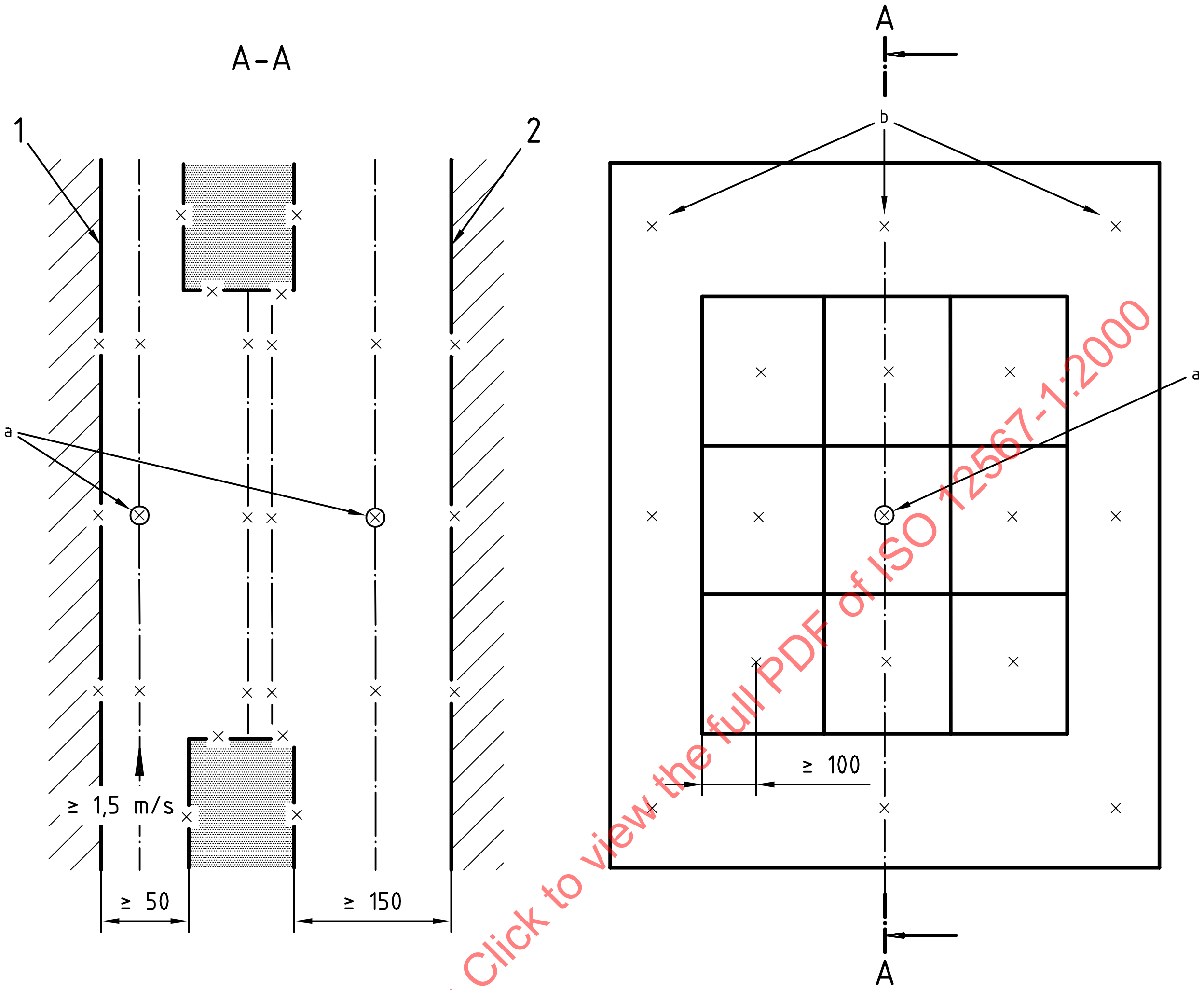
It is recommended that the same layout of the surface temperature grid on the calibration panel is used (a minimum of 9) for air temperature and baffle plate measurements.

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 50 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.

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 is not 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 5) 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

X 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 5 — Location of temperature and air speed sensors

If the dimensions of the metering box are such that its perimeter contacts lie closer to the aperture edges than 200 mm, then it is inappropriate to measure the warm surface temperatures of the surround panel. In this instance, it is permissible to use warm side average air temperatures as replacement for surround panel average warm surface temperature to determine $\Delta\theta_{s,sur}$ in the calibrations in 6.2.4 [equation (8)]. If this is done, then the same procedure shall be adopted to correct for the surround panel influences in the subsequent measurements [see 6.3, equation (12)].

6 Test procedure

6.1 General

The general operating procedure for the hot box measurements shall follow that specified in ISO 8990, and in addition, the following requirements shall be complied with.

6.2 Calibration measurements

6.2.1 General

These 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 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. By 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 like windows or doors, the mean heat transfer conditions over the measured area will be 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 ISO 8990 and annex A 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. $(0{,}17 \pm 0{,}01)$ m²·K/W or appropriate to national standards. Thereafter the fan speed settings and/or the throttling devices shall remain constant for all subsequent calibration measurements. The 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):

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

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):

$$q_{cal} = \frac{\Delta\theta_{s,cal}}{R_{cal}} \tag{2}$$

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

$$R_{cal} = \sum \frac{d_j}{\lambda_j} \tag{3}$$

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 are 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 needed in order to determine the environmental temperatures (according to the procedures given in annex A and ISO 8990). Surface temperature measurements on the calibration panel at different densities of heat flow rate will allow the determination of the surface coefficients of heat transfer. The surface resistances are calculated using equations (4) and (5):

$$R_{si} = \frac{\theta_{ni,cal} - \theta_{si,cal}}{q_{cal}} \tag{4}$$

$$R_{se} = \frac{\theta_{se,cal} - \theta_{ne,cal}}{q_{cal}} \tag{5}$$

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 according to the procedure given in annex A and determine the convective fraction, F_c, using the 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 will be used by interpolation for the determination of the environmental temperatures of all subsequent measurements of test specimens using equation (7):

$$\theta_n = F_c \theta_c + (1 - F_c)\, \theta_r \qquad (7)$$

Annex E gives an analytical calibration procedure as an alternative. From detailed heat balance equations, analytical functions are established for the convective and radiative part of the density of heat flow rate, q_{cal}. These functions are 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} ≈ 60 mm), calculate and plot the thermal resistance, R_{sur}, of the surround panel as a function of its mean temperature. From the heat flows shown in Figure 6, the equations (8), (9) and (10) are derived:

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

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):

$$\Phi_{cal} = A_{cal} q_{cal} \qquad (9)$$

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):

$$\Phi_{edge} = L_{edge} \Psi_{edge} \Delta\theta_c \qquad (10)$$

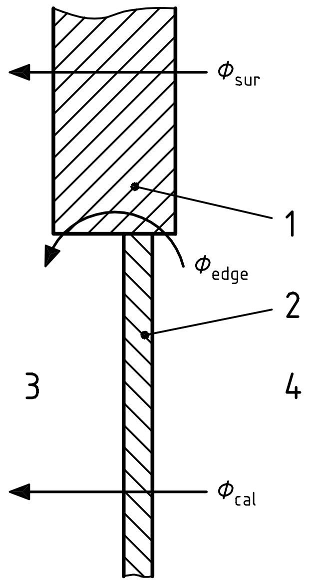
where

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.



Key

1 Surround panel

2 Calibration panel

3 Cold side

4 Warm side

Figure 6 — Surround panel and boundary effects

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 $\Delta\theta_c \approx (20 \pm 2)$ K, or in accordance with national standards. Areas of condensation or ice formation on the specimen may 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):

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

where Φ_{sur} is the heat flow rate through the surround panel in watts, given by:

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

where

Φ_{edge} is the edge zone heat flow rate according equation (10), in watts; the actual value for Ψ_{edge} shall be taken from annex B, Table B.2;

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

R_{sur} is the thermal resistance of the surround panel, in m²·K/W, determined by calibration (see example given in annex D, Figure D.1).

The measured overall thermal transmittance, U_m, expressed in W/(m²·K), of the test specimen shall be calculated using equation (13):

$$U_m = \frac{q_{sp}}{\Delta\theta_n} \tag{13}$$

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 m²·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 standardardized thermal transmittance, U_{st}, in W/(m²·K), using equation (14):

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

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

NOTE A worked example of a calibration measurement and window test is given in annex D.

7 Test report

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

a) All details necessary to identify the product tested: height, width, thicknesses including dishing or bowing of the glazing unit under laboratory conditions and immediately after the test; 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; 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, etc.] and the position relevant to the surround panel.

b) Method of calibration: summary details of the range of calibrations appropriate to these tests (calibration curves or analytical calibration functions).

c) Results of measurements:

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

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

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

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

— the measured thermal transmittance, U_m, as obtained from the tests;

— 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;

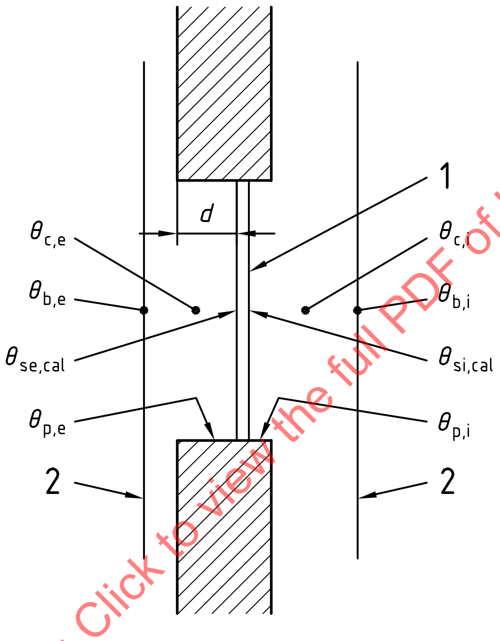
— estimation of the approximate error of the measurement (e.g. procedure given in reference [8] of bibliography).

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

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

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

θ_b is the average surface temperature of the baffle, in degrees Celsius;

θ_c is the 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 one of the following equations.

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

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

b) If $|\theta_b - \theta_p| \leqslant 5$ 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):

$$\alpha_{cb} \approx \varepsilon_{cal}\varepsilon_{b}\left[f_{cb} + \left(1 - \varepsilon_{p}\right) f_{cp} f_{pb} \right] \quad \text{(A.8)}$$

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

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 means from calibration panel to baffle;

cp means from calibration panel to surround panel reveal;

pb means from surround panel reveal to baffle;

bp means from baffle to surround panel reveal;

pp means 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):

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

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				
	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				
	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).

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

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

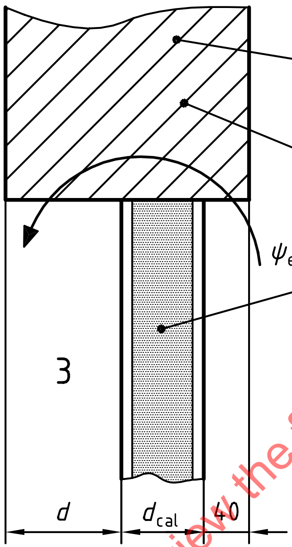
For other geometries, a detailed radiation heat exchange calculation procedure shall be used (see references [9] or [10] for details).

Annex B
(normative)

Linear thermal transmittance of the edge zone

See Figures B.1 and B.2 and Table B.1.

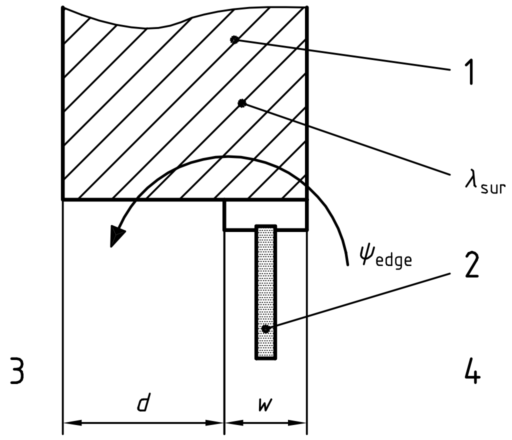
Dimensions in millimetres



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.						

Table B.2 — Linear thermal transmittance for test specimen

w mm	d mm	Ψ_{edge} 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)			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 (CTS)

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 that 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 [11]).

C.1.2 Materials

C.1.2.1 Core material, 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, 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.[1)]

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 1,2 m × 1,2 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.

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.)

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

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

C.1.3.2.5 Tape the edges of 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 strages in the fabrication of the calibration panels.

Determine the EPS sheet thickness and the average glazed panel thickness as precisely as is possible in practice. 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

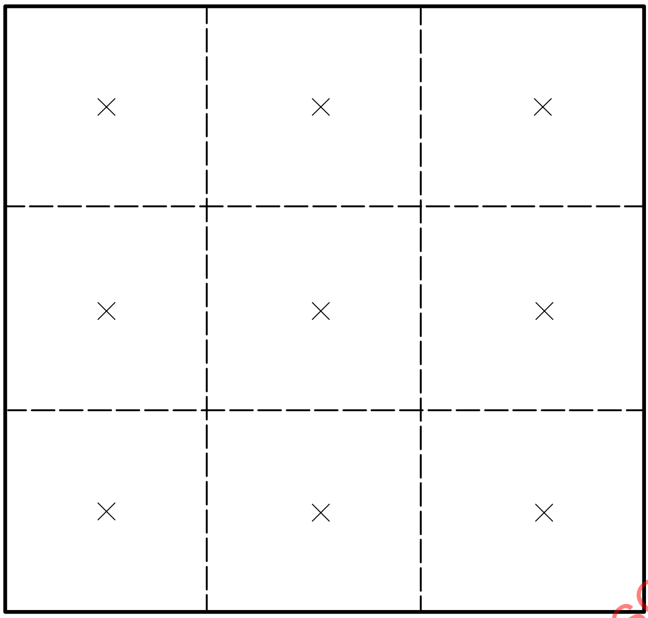
Thermocouples should be made of wire with a maximum diameter of 0,5 mm.

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

X Temperature sensors

NOTE Figure is not to scale.

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

C.2 Calibration transfer standard design

A large heat flux transducer is used in the calibration of the surface heat transfer coefficients (see reference [5]). The calibration transfer standard (CTS) consists of a homogeneous, well-characterized, core calibration material made from insulation board that has a known thermal conductivity, measured by the test methods in accordance with references [12] or [13]. A recommended calibration transfer standard 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. [It should be noted that the surface emissivity of the polycarbonate has to be precisely measured and used where appropriate in calculations requiring the calibration transfer standard'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 calibration transfer standard, measure the thermal conductivity of the material used for the core of the calibration transfer standard in a guarded hot plate (see Test Method C 177 in reference [12]) or a heat flow meter (see Test Method C 518 in reference [13]) 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 calibration transfer standard m	Area of calibration transfer standard m²	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 calibration transfer standard. 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 calibration transfer standard 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[2)] to the glazing facing inner surfaces. After the epoxy has dried and all epoxy been 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[3)] 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 will 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 calibration transfer standard 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.

2) Loctite Minute Bond 312 is an example of a suitable product available commercially.

3) 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 International Standard and does not constitute an endorsement by ISO of these products.

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 are 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 has been 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 according to ISO 8302. The measured data are:

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

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

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 values			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	4,80			4,80		
Test number			2	1[a]	3	5	4	6
Cold temperatures								
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 temperatures								
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

Values resulting from mounting instructions			Remarks	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 λ = 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: ε_{cal} = 0,84; ε_p = 0,92; ε_b = 0,95.

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

Data element		Remarks	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		Remarks	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. to D.3. The following regression curves have been derived by least-square fits from the data set:

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

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

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

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