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EN 12412-2

July 2003

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English version

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

Performance thermique des fenêtres, portes et fermetures - Détermination du coefficient de transmission thermique par la méthode de la boîte chaude - Partie 2: Encadrements

Wärmetechnisches Verhalten von Fenstern, Türen und Abschlüssen - Bestimmung des Wärmedurchgangskoeffizienten mittels des Heizkastenverfahrens - Teil 2: Rahmen

This European Standard was approved by CEN on 2 May 2003.

CEN members are bound to comply with the CEN/CENELEC Internal Regulations which stipulate the conditions for giving this European Standard the status of a national standard without any alteration. Up-to-date lists and bibliographical references concerning such national standards may be obtained on application to the Management Centre or to any CEN member.

This European Standard exists in three official versions (English, French, German). A version in any other language made by translation under the responsibility of a CEN member into its own language and notified to the Management Centre has the same status as the official versions.

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EUROPEAN COMMITTEE FOR STANDARDIZATION
COMITÉ EUROPÉEN DE NORMALISATION
EUROPÄISCHES KOMITEE FÜR NORMUNG

Management Centre: rue de Stassart, 36 B-1050 Brussels

Ref. No. EN 12412-2:2003 E

Contents

Foreword

This document EN 12412-2:2003 has been prepared by Technical Committee CEN /TC 89, "Thermal performance of buildings and building components" the secretariat of which is held by SIS.

This European Standard shall be given the status of a national standard, either by publication of an identical text or by endorsement, at the latest by January 2004, and conflicting national standards shall be withdrawn at the latest by January 2004.

This standard is one of a series of standards on calculation and measurement methods for the design and evaluation of the thermal performance of buildings and building components.

Annexes A and B are normative. Annex C is informative.

According to the CEN/CENELEC Internal Regulations, the national standards organizations of the following countries are bound to implement this European Standard: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Luxembourg, Malta, Netherlands, Norway, Portugal, Slovakia, Spain, Sweden, Switzerland and the United Kingdom.

Introduction

The method given in this European Standard provides data on frames that can be used in calculations of the overall thermal performance of windows and doors according to EN ISO 10077-1, *Thermal performance of windows, doors and shutters – Calculation of thermal transmittance – Part 1: Simplified method (ISO 10077-1).*

1 Scope

This European Standard specifies a method, based on EN ISO 8990 and EN ISO 12567-1, to measure the thermal transmittance of frame and sash components of windows and doors, including mullions and transoms.

The thermal bridging effect of window or door components (handles, hinges, closing devices, etc.) is included.

The test procedure is designed to take into account the whole developed area of the frame or sash surface, but excludes the influence of the thermal bridge introduced through the spacer in sealed glazing units.

Edge effects occurring outside of the perimeter of the specimen are excluded. Furthermore, energy transfer due to solar radiation is not taken into account, and air leakage is excluded.

The measurements are performed under defined conditions to facilitate the comparison of measured values.

Information on the design of the calibration transfer standard is given in EN ISO 12567-1.

2 Normative references

This European Standard incorporates by dated or undated reference, provisions from other publications. These normative references are cited at the appropriate places in the text, and the publications are listed hereafter. For dated references, subsequent amendments to or revisions of any of these publications apply to this European Standard only when incorporated in it by amendment or revision. For undated references the latest edition of the publication referred to applies (including amendments).

EN 1946-4, *Thermal performance of building products and components – Specific criteria for the assessment of laboratories measuring heat transfer properties – Part 4: Measurements by hot box methods.*

prEN 12519:1996, *Windows and doors – Terminology.*

EN 12664, *Thermal performance of building materials and products – Determination of thermal resistance by means of guarded hot plate and heat flow meter methods – Dry and moist products of medium and low thermal resistance.*

EN ISO 7345:1995, *Thermal insulation – Physical quantities and definitions (ISO 7345:1987).*

EN ISO 8990:1996, *Thermal insulation – Determination of steady-state thermal transmission properties – Calibrated and guarded hot box (ISO 8990:1994).*

EN ISO 9288:1996, *Thermal insulation – Heat transfer by radiation – Physical quantities and definitions (ISO 9288:1989).*

EN ISO 12567-1:2000, *Thermal performance of windows and doors – Determination of thermal transmittance by hot box method - Part 1: Complete windows and doors (ISO 12567-1:2000).*

3 Terms, definitions, symbols, units and subscripts

3.1 Terms and definitions

For the purposes of this European Standard, the terms and definitions given in prEN 12519:1996, EN ISO 7345:1995, EN ISO 8990:1996 and EN ISO 9288:1996 apply.

3.2 Symbols and units

Symbol	Quantity	Unit
A	area	m^2
d	thickness or depth	m
F	fraction	–
f	view factor	–
H	height	m
h	surface coefficient of heat transfer	$W/(m^2 \cdot K)$
L	perimeter length	m
l	length	m
q	density of heat flow rate	W/m^2
R	thermal resistance	$m^2 \cdot K/W$
T	thermodynamic temperature	K
ΔT, $\Delta \theta$	temperature difference	K
U	thermal transmittance	$W/(m^2 \cdot K)$
v	air velocity	m/s
w	width	m
α	radiation factor	–
ε	hemispherical emissivity	–
θ	Celsius temperature	°C
Λ	thermal conductance	$W/(m^2 \cdot K)$
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	$W/(m \cdot K)$

3.3 Subscripts

b	baffle
c	convection (air)
ca	calibration
e	external, usually cold side
ed	edge zone
f	frame
fi	infill with known thermal properties

hb	hot box
i	internal, usually warm side
in	input
m	measured
me	average/mean
n	environmental (ambient)
ne	environmental (ambient external)
ni	environmental (ambient internal)
p	reveal of surround panel
r	radiation (mean)
s	surface
sp	specimen
sur	surround panel
t	total

4 Principle

The thermal transmittance of a frame is determined directly by measurement under standardised conditions using the calibrated or guarded hot box method according to EN ISO 8990 and EN ISO 12567-1. The requirements of EN ISO 8990 shall be complied with in addition to those given in this standard. The method may be applied to complete window or door frames (see 5.3.1) or to profile sections including mullions, transoms etc. (see 5.3.2).

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 5).

The principal heat flows through the surround panel and the calibration panel (or test specimen) are shown in Figure 8. The boundary edge heat flow due to the location of the calibration panel in the surround panel is determined separately as a linear thermal transmittance, Ψ.

The procedure in this standard 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 EN ISO 12567-1:2000, annex B.

5 Requirements for test specimen and apparatus

5.1 General

The test apparatus shall conform to the requirements specified in EN 1946-4, EN ISO 8990 and EN ISO 12567-1.

5.2 Surround panels

For details see EN ISO 12567-1:2000, 5.2.

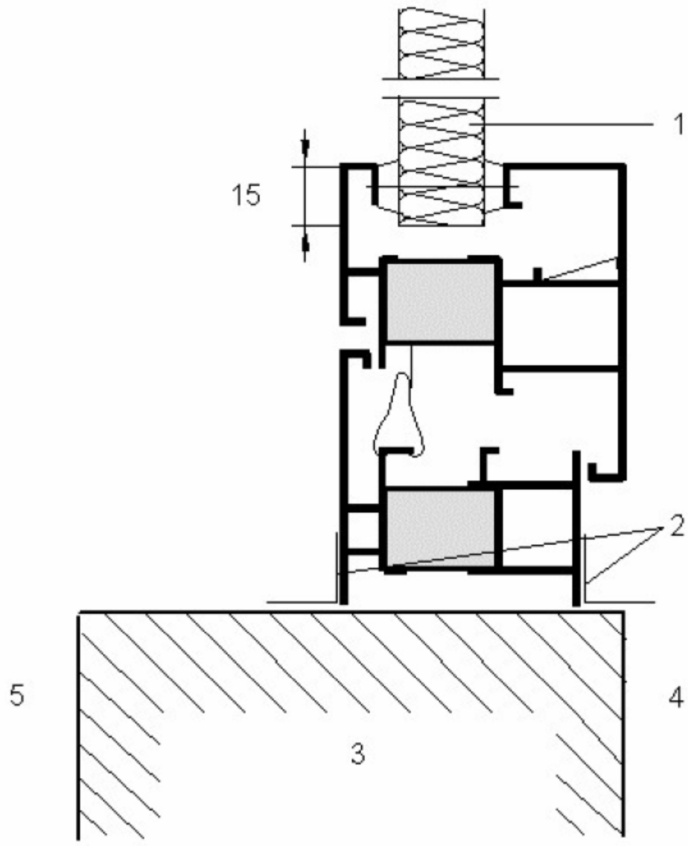
5.3 Specimen requirements and location

5.3.1 Complete frames for windows and doors

Specimen sizes should be representative (typical) of those found in practice. For standardised tests on window frames the overall sizes recommended are 1230 mm (width) by 1480 mm (height). Further requirements are laid down in EN ISO 12567-1:2000, 5.3.

To ensure consistency of measurement, the specimen shall be located as follows. The specimen with panel shall fill the surround panel aperture, which shall be located centrally. 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 (see Figures 1, 2 and 3).

Dimensions in millimetres

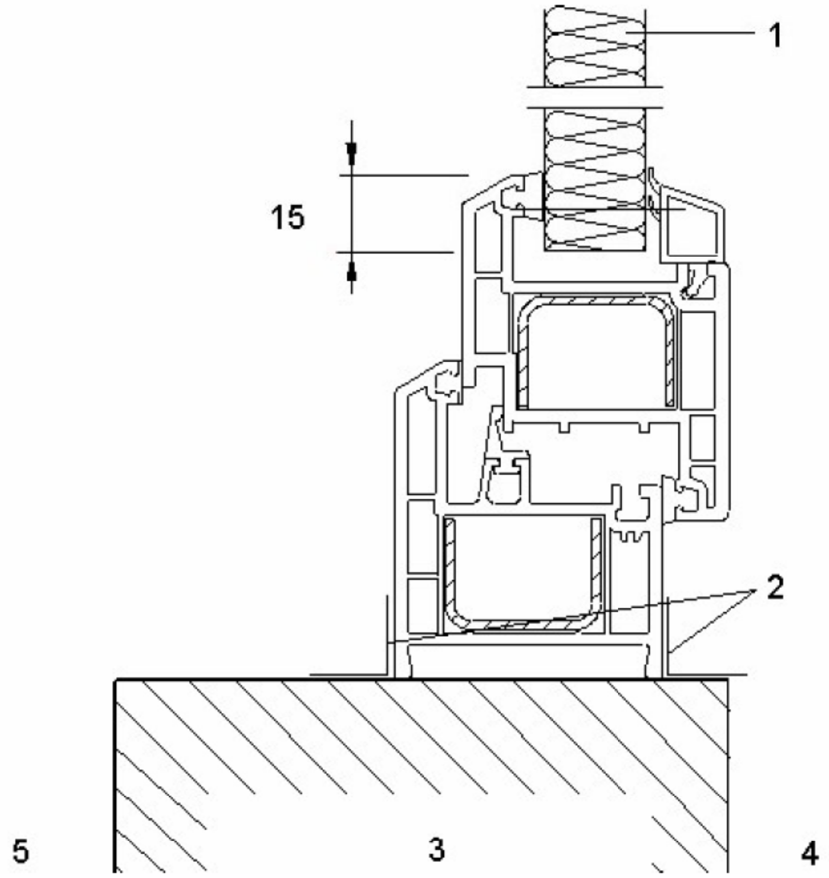


Key

1 Infill element of insulating material
2 Adhesive tape
3 Aperture
4 Warm side
5 Cold side

Figure 1 — Mounting of specimen in the aperture – Metal frame

Dimensions in millimetres

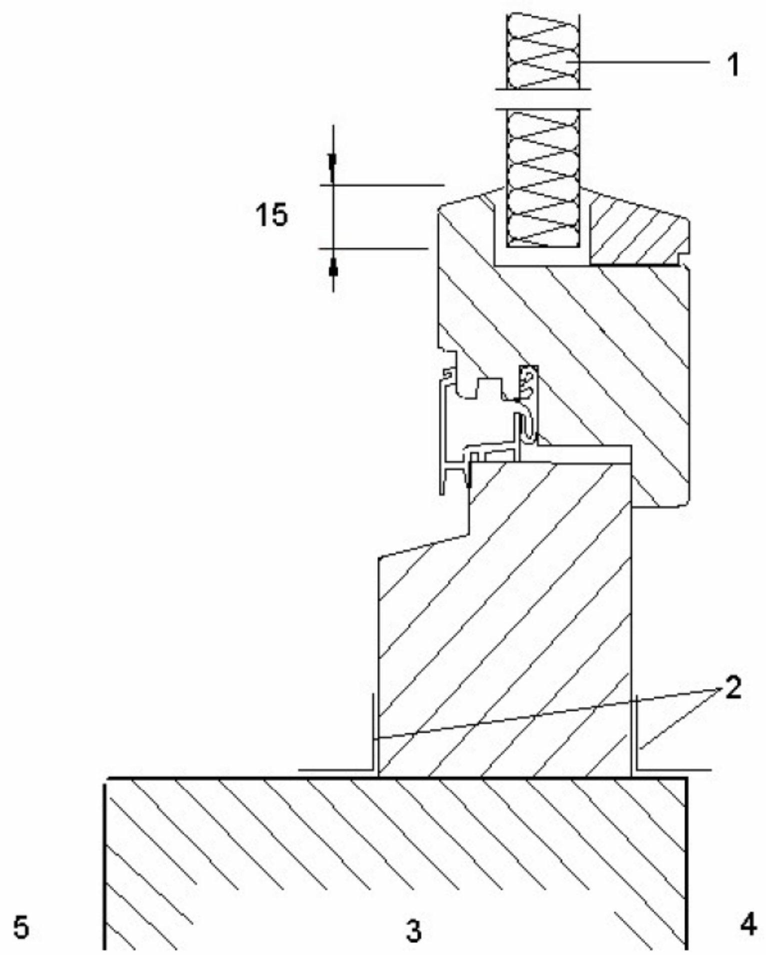


Key

1 Infill element of insulating material
2 Adhesive tape
3 Aperture
4 Warm side
5 Cold side

Figure 2 — Mounting of specimen in the aperture – PVC frame

Dimensions in millimetres



Key

1 Infill element of insulating material
2 Adhesive tape
3 Aperture
4 Warm side
5 Cold side

Figure 3 — Mounting of the specimen in the aperture – Wood frame

The aperture should be at least 200 mm from the inside surfaces of the cold and hot boxes to avoid or limit edge heat flow corrections, and to allow room for the guarded hot box (where applicable).

Any glazing or opaque infill panels in windows and doors shall be replaced by insulating panels (see Figures 1, 2 and 3). Thermocouples to measure the surface temperature on the infill insulation shall be placed as shown in Figure 6.

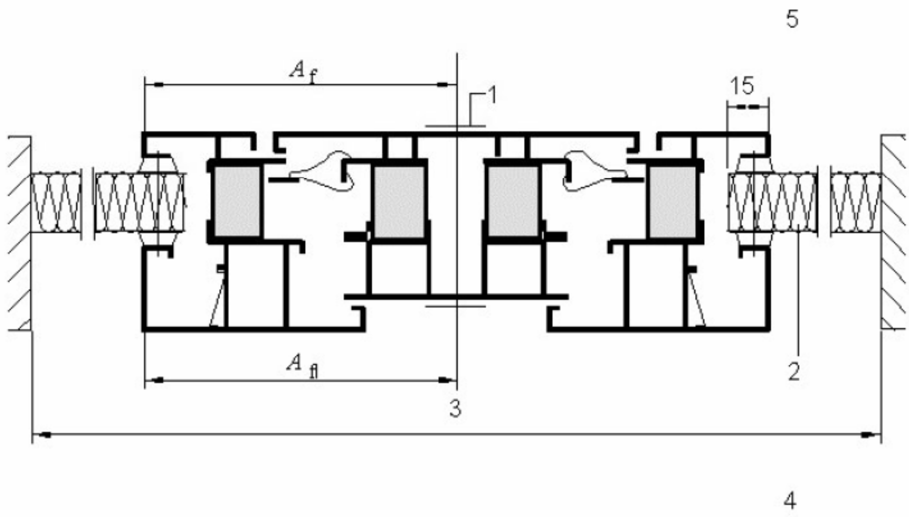
All surround panel thermocouples should be located centrally (see Figure 6).

For further information see EN ISO 12567-1.

5.3.2 Frame and sash, transom or mullion profile sections

The frame, mullion or transom of a window or door system shall be installed vertically in the surround panel aperture. The internal specimen 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 (see Figure 4).

Dimensions in millimetres



Key

1 Adhesive tape
2 Infill element of insulating material
3 Projected area A_t of the frame and infill insulation
4 Warm side
5 Cold side

Figure 4 — Combination of sashes and frames

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

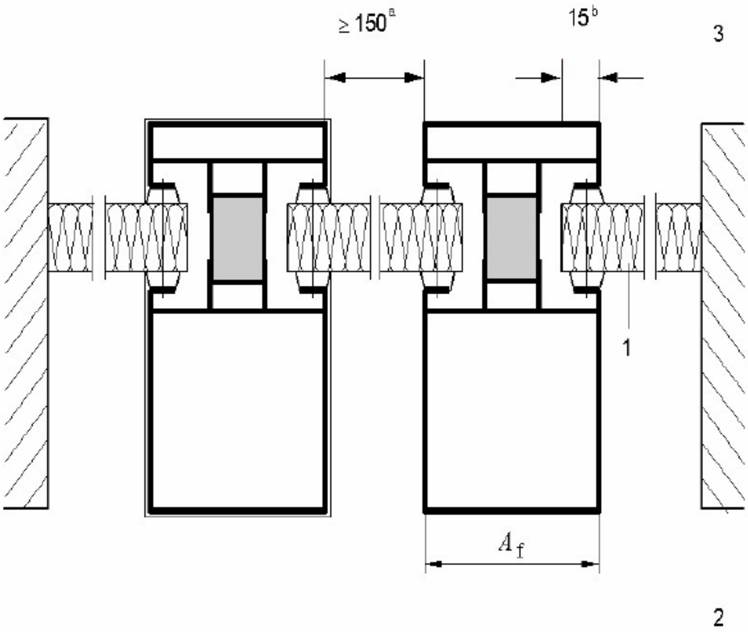
The length of the profile sections should be 1480 mm.

If the specimens usually form part of a combination of several frame profiles, e.g. sash and frame, the complete units shall be tested, inclusive of any hinges, seals, etc.

The sash and frame profile sections shall be connected with at least two hinges. Additionally, the profile sections shall be fixed without causing thermal bridging.

If the frame area forms less than 30 % of the aperture area of the hot box, two or more frames shall be installed so that the total frame area is at least 30 % of the aperture area, with a recommended distance between profile sections of 150 mm (see Figure 5).

Dimensions in millimetres



Key

1 Infill insulation
2 Warm side
3 Cold side
a Recommended dimension
b The extent of penetration of the infill insulation may be smaller than 15 mm only if the design does not allow 15 mm; in that case the actual penetration depth shall be stated in the test report

Figure 5 — Installation of more than one frame section in the aperture

The connection of frame and insulating panels, and the joining of frames, are shown in Figures 4 and 5.

The surface of specimens shall be treated as for the normal application of the product.

The area remaining between the aperture of the hot box and the specimen shall be filled with an infill insulation with known thermal conductivity. The thermal conductivity should not be higher than 0,035 W/(m·K).

The thermal conductivity of the infill insulation shall be obtained by measurement according to EN 12664 (guarded hot plate apparatus) or by using materials with certified properties from an accredited source.

Thermocouples to measure the surface temperature shall be centrally located as shown in Figure 7.

For further information see EN ISO 12567-1.

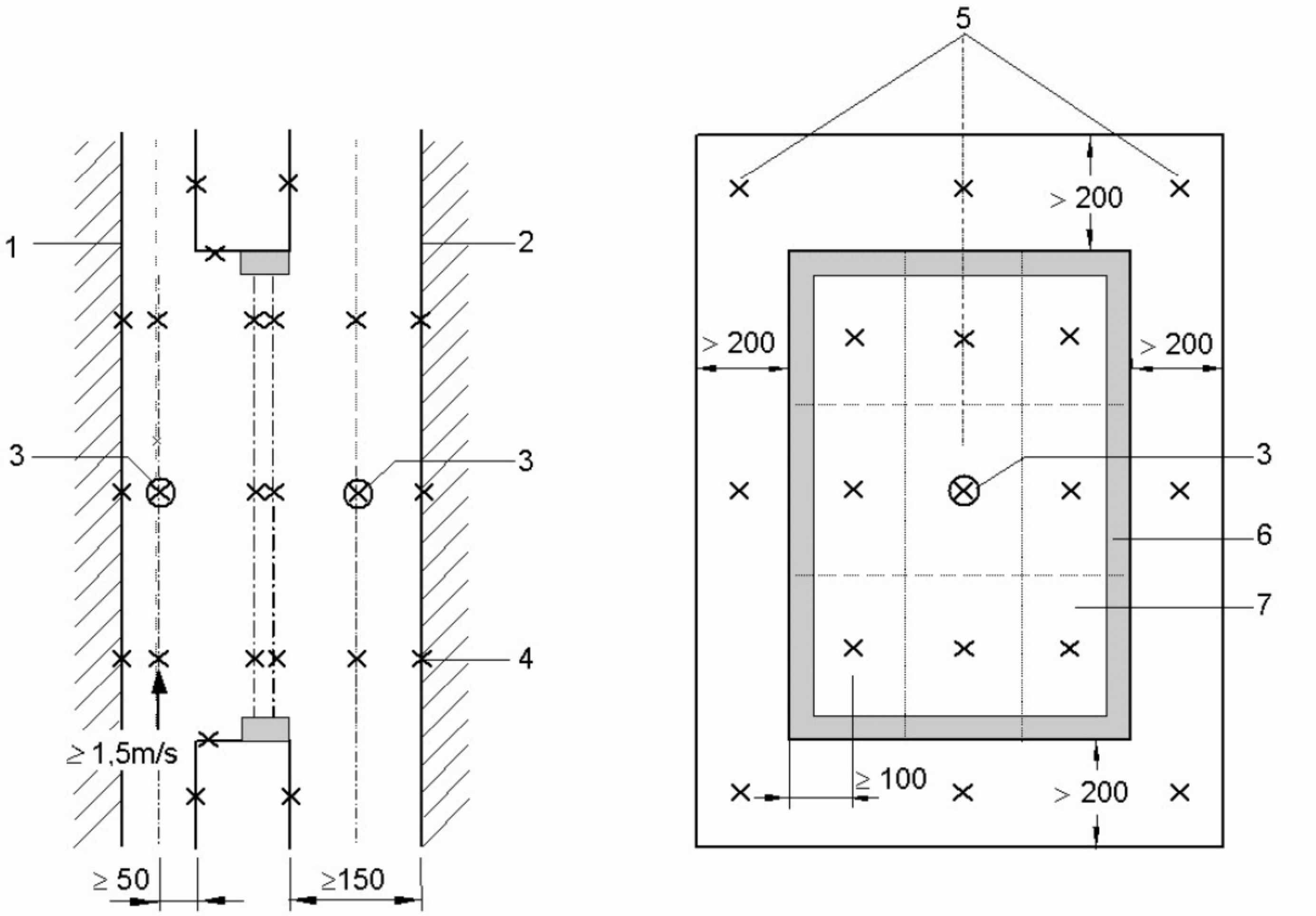
5.4 Calibration panels

The calibration panel shall be mounted as shown in Figure 8. For further details see 5.5 and EN ISO 12567-1:2000, 5.4.

5.5 Temperature measurement and baffle positions

For details see EN ISO 12567-1:2000, 5.6.

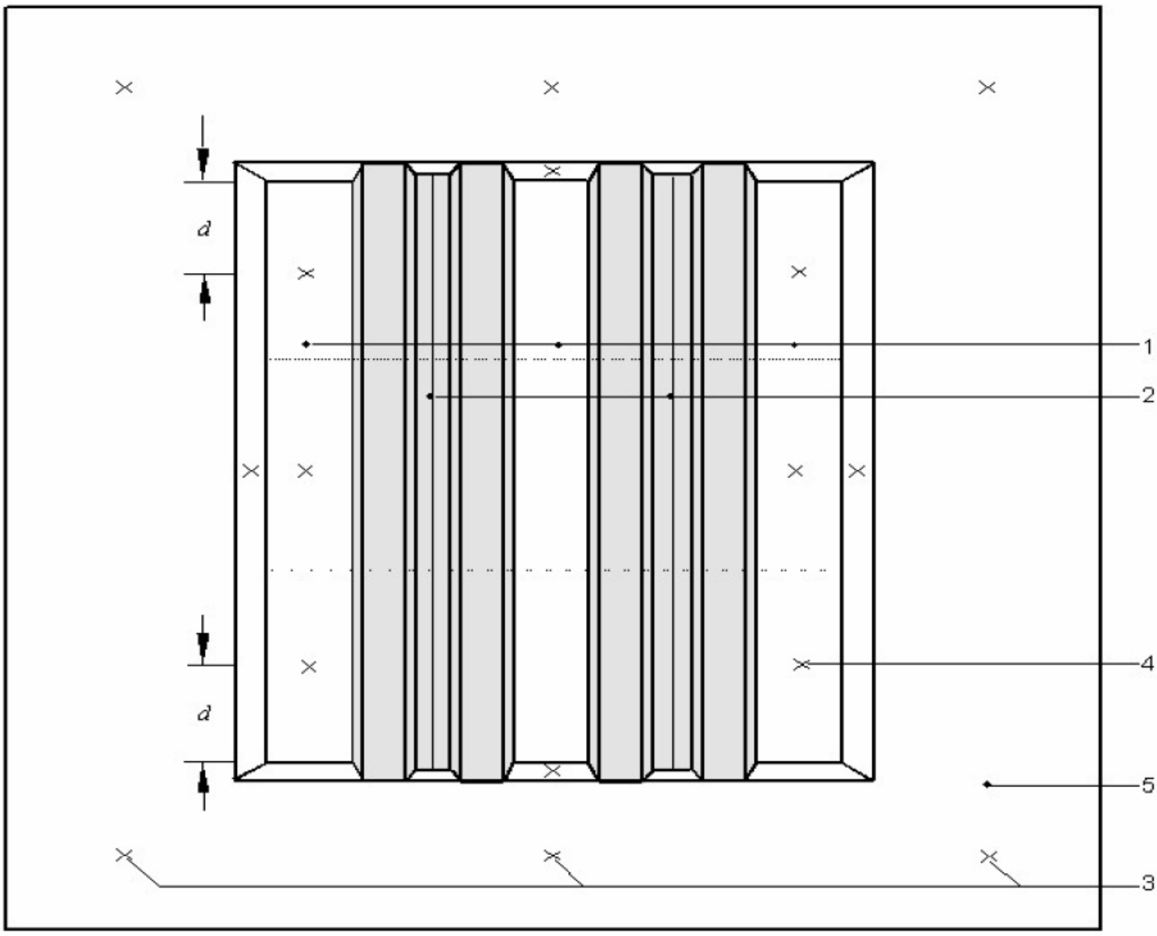
Dimensions in millimetres



Key

1 Cold side baffle
2 Warm side baffle
3 Air speed sensor
4 Temperature sensors (×)
5 Surround panel thermocouples
6 Test specimen
7 Infill insulation

Figure 6 — Location of temperature and air speed sensors for measurements on complete frames for windows and doors



Key

1 Infill insulation
2 Test specimen
3 Temperature sensors (×)
4 Temperature sensors (×)
5 Surround panel

NOTE Dimension d is half of 1/3 of the height of the infill insulation

Figure 7 — Location of temperature sensors for measurements on profile sections

6 Test procedure

6.1 General

Except as provided herein, the test procedure shall conform with EN ISO 12567-1:2000, 6.2 and 6.3. An example of the required calculations is given in annex C.

6.2 Calibration measurements

6.2.1 General

Calibration measurements 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 rate, which cover the required range of specimen testing.

The calibration measurements should be carried out at three different mean air temperatures $\theta_{c,me}$ (where $\theta_{c,me}$ is $(\theta_{c,i} + \theta_{c,e})/2$) 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 window frames or door frames, 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 calibration panels should be as specified in EN ISO 12567-1:2000, C.1 and the calibration measurements shall be carried out as specified in EN ISO 12567-1:2000, 6.2 (see also Figure 8).

The first calibration test shall be made with the thin panel ($d_{ca} \approx 20$ mm) at a mean temperature of approximately 10°C and a temperature difference, $\Delta\theta_c$ between warm and cold sides, of (20 ± 2) K (see annex A for determination of the environmental temperatures, EN ISO 8990:1996 and EN ISO 12567-1:2000, annex A).

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) $R_{s,t} = 0{,}17 \pm 0{,}01$ m^2·K/W. Thereafter the fan speed settings and/or the throttling devices shall remain constant for all subsequent calibration measurements. The set-up used for the calibration procedure shall be used for all tests with specimens of frames.

6.2.2.2 Calculation

Calculate the total surface thermal resistance of the warm and cold side, $R_{s,t}$, expressed in m^2·K/W, using Equation (1):

$$R_{s,t} = \frac{\Delta\theta_{n,ca} - \Delta\theta_{s,ca}}{q_{ca}} \tag{1}$$

where

$\Delta\theta_{n,ca}$ is the difference between the environmental temperatures on each side of the calibration panel, in K, calculated in accordance with annex A;

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

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

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

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

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

The total surface resistance, $R_{s,t}$, shall be plotted as a function of the density of heat flow rate, q_{ca} through the calibration panel. These characteristics are used to determine the total surface resistance for all subsequent measurements on test specimens.

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, EN ISO 8990 and EN ISO 12567-1:2000, annex A). Surface temperature measurements on the calibration panel at different densities of heat flow rate allows the determination of the surface coefficients of heat transfer. The surface resistances are calculated using Equations (4) and (5).

$$R_{\mathrm{si,\,t}} = \frac{\Delta\theta_{\mathrm{ni,ca}} - \Delta\theta_{\mathrm{si,ca}}}{q_{\mathrm{ca}}} \tag{4}$$

$$R_{\mathrm{se,\,t}} = \frac{\Delta\theta_{\mathrm{ne,ca}} - \Delta\theta_{\mathrm{se,ca}}}{q_{\mathrm{ca}}} \tag{5}$$

where

q_{ca} is the density of heat flow rate through the calibration panel, in W/m²;

$\theta_{\mathrm{ni,ca}}$ is the environmental temperature of the warm side, in °C;

$\theta_{\mathrm{si,ca}}$ is the warm side surface temperature of the calibration panel, in °C;

$\theta_{\mathrm{se,ca}}$ is the cold side surface temperature of the calibration panel, in °C;

$\theta_{\mathrm{ne,ca}}$ is the environmental temperature of the cold side, in °C.

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 EN ISO 12567-1:2000, annex A, and determine the convective fraction F_{c} using Equation (6):

$$F_{\mathrm{c}} = \frac{h_{\mathrm{c}}}{h_{\mathrm{c}} + h_{\mathrm{r}}} \tag{6}$$

where

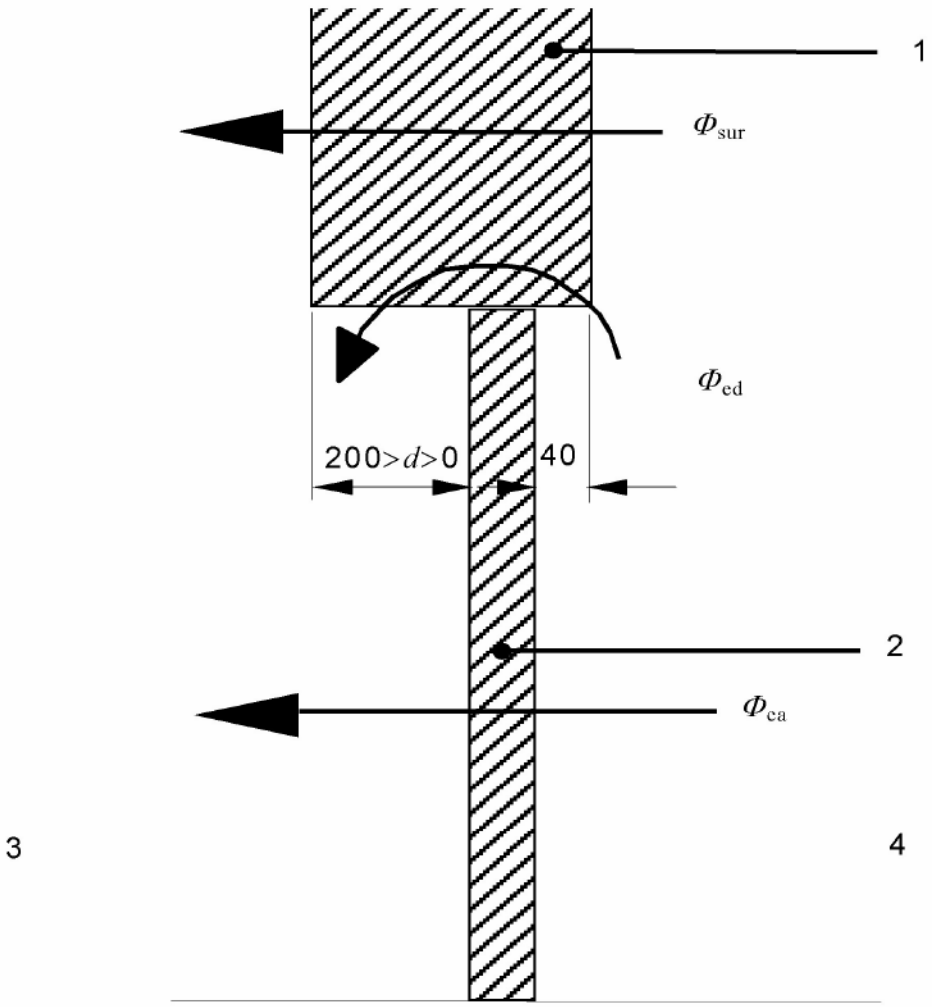
h_{c} is the convective coefficient of heat transfer, in W/(m²·K);

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_{ca} (density of heat flow rate through 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):

$$\theta_{\mathrm{n}} = F_{\mathrm{c}}\theta_{\mathrm{c}} + (1 - F_{\mathrm{c}})\,\theta_{\mathrm{r}} \tag{7}$$

Dimensions in millimetres



Key

1 Surround panel
2 Calibration panel
3 Cold side
4 Warm side

Figure 8 — Surround panel and boundary effects

6.2.4 Surround panel and edge effects

The major difference compared to the procedures given in EN ISO 12567-1 is that a correction for a change in the total surface resistance is not made and so a graph of the density of heat flow rate against the total surface resistance does not need to be drawn.

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

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

where

A_{sur} is the projected area of the surround panel, in m^2;

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

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 W, (see EN ISO 8990);

Φ_{ca} is the heat flow rate through the calibration panel, in W, given by:

$$\Phi_{ca} = A_{ca}\, q_{ca} \tag{9}$$

where

A_{ca} is the projected area of the calibration panel, in m^2;

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

Φ_{ed} is the heat flow rate through the edge zone between calibration panel and surround panel, in W, given by:

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

where

L_{ed} is the perimeter length between surround panel and specimen, in m;

Ψ_{ed} is the linear thermal transmittance of the edge zone between surround panel and specimen, in W/(m·K); values of Ψ_{ed} shall be taken from Table B.2 for measurements on complete frames described in 5.3.1 and Table B.3 for measurements on frame profiles described in 5.3.2;

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

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.

NOTE 1 The calculation of environmental temperatures is described in EN ISO 12567-1:2000, annex A.

NOTE 2 If the internal and external projected areas are different, the larger of the two is used.

NOTE 3 A worked example is given in annex C.

6.3 Measurement procedure for test specimens

The measurement of the test specimens shall be made under the same conditions as those used in the corresponding calibrations described in EN ISO 12567-1:2000, 6.2.1, at a mean temperature of approximately 10°C.

The density of heat flow rate q_t, expressed in W/m^2, through the infill insulation and frame during the measurement shall be calculated using Equation (11):

$$q_t = \frac{\Phi_{in} - \Phi_{sur} - \Phi_{ed}}{A_t} \tag{11}$$

where

A_t is the projected area of the frame and the infill area, in m^2;

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 W; (see EN ISO 8990:1996, 2.9.3.3);

Φ_{ed} is the edge zone heat flow rate according to Equation (10), in W; the actual value for Ψ_{ed} shall be taken from Tables B.2 or B.3;

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

$$\Phi_{sur} = \frac{A_{sur}\,\Delta\theta_{s,sur}}{R_{sur}} \tag{12}$$

where

$\Delta\theta_n$ is the difference between the environmental temperatures on each side of the system under test, in K;

A_{sur} is the projected area of the surround panel, in m^2;

R_{sur} is the thermal resistance of the surround panel, in m^2·K/W, determined by calibration (see example in annex C, Figure C.1).

The measured overall thermal transmittance $U_{m,t}$,expressed in W/(m^2·K), of the infill insulation and frame shall be calculated by Equation (13):

$$U_{m,t} = \frac{q_t}{\Delta\theta_n} \tag{13}$$

where

q_t is the density of heat flow rate in the measurement of the infill insulation and frame, in W/m^2.

The overall thermal transmittance of the frame, U_f, is given by:

$$U_f = \frac{U_{m,t}\,A_t\,\Delta\theta_n - \Lambda_{fi}\,\Delta\theta_{s,fi}\,A_{fi}}{A_f\,\Delta\theta_n} \tag{14}$$

where

$U_{m,t}$ is the measured thermal transmittance of the infill insulation and the frame, in W/(m^2·K);

A_f is the frame area; the frame area is the larger of the two projected areas seen from both sides, in m^2;

A_{fi} is the remaining area of the calibrated infill insulation in the plane of measurement ($A_{fi} = A - A_f$), in m^2, (see Figure 9);

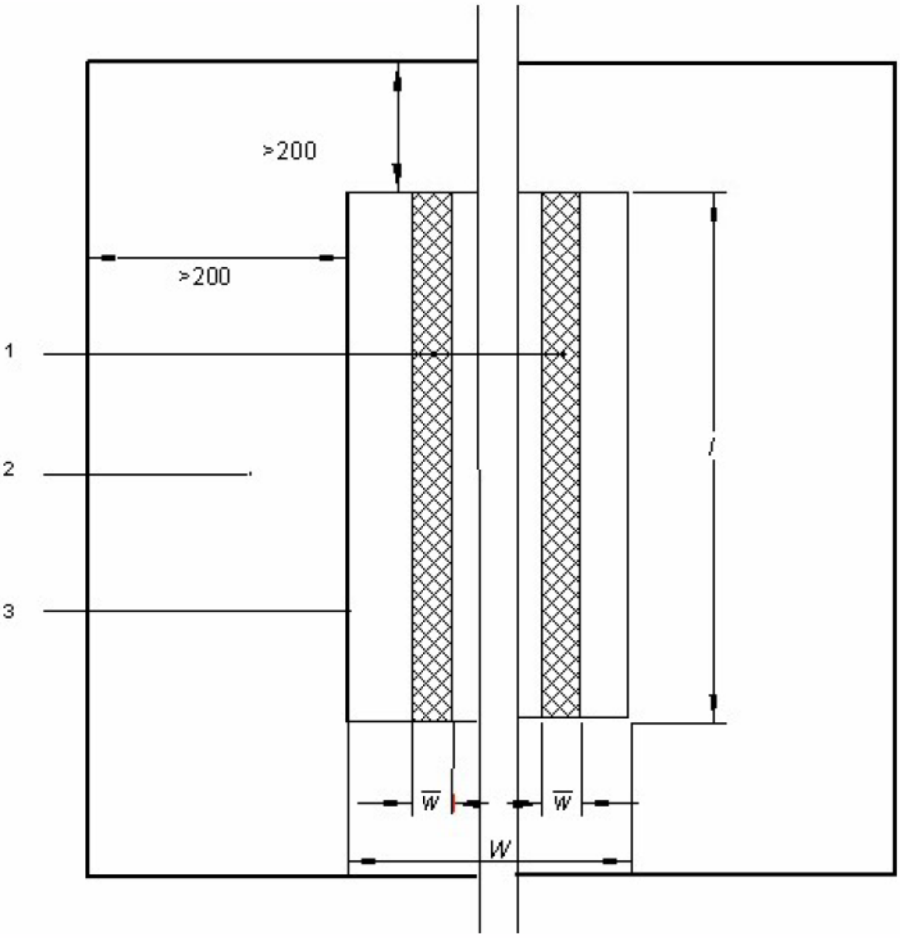
A_t is the projected area of the metering area, in m^2;

$\Delta\theta_n$ is the difference between the environmental temperatures on each side of the system under test, in K;

Λ_{fi} is the thermal conductance of the infill insulation, in W/(m^2·K);

$\Delta\theta_{s,fi}$ is the difference of the temperatures between the surfaces of the infill element, in K.

Dimensions in millimetres



Key

1 Test specimen
2 Surround panel
3 Aperture

Figure 9 — Aperture

The area of the aperture is $$A = w\,l \tag{15}$$

The area of infill is $$A_{\mathrm{fi}} = (wl) - \sum_i (\overline{w}_i\, l_i) \tag{16}$$

The projected area of the frame is $$A_{\mathrm{f}} = \sum_i (\overline{w}_i\, l_i) \tag{17}$$

7 Test report

The test report shall contain:

a) details of apparatus as required by EN ISO 8990 and EN ISO 12567-1;

b) identification of specimen (height, width, thickness);

c) sketch showing the structure of the specimen (including frame composition and geometry, sashes, thermal break etc.);

d) summary details of the range of calibrations appropriate to the test;

e) test conditions and result:

— mean environmental temperature on hot side θ_{ni} ;

— mean environmental temperature on cold side θ_{ne} ;

— air speed v_e, on cold side;

— the measured thermal transmittance U_f, as obtained from the test.

Thermal transmittances shall be expressed in W/(m^2·K) rounded to two significant figures.

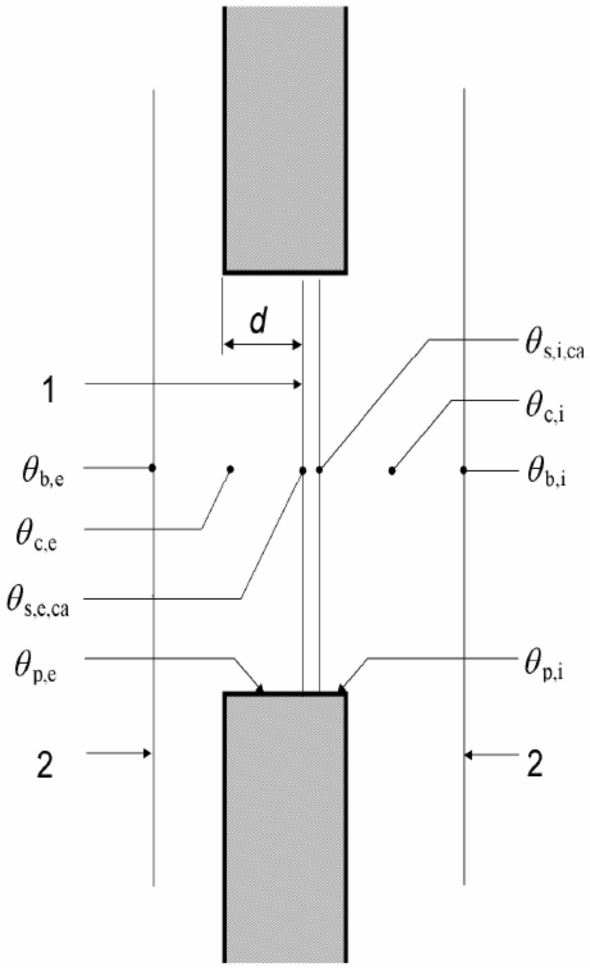
Annex A
(normative)

Determination of environmental temperature

A.1 General

The procedure in EN ISO 12567-1:2000, annex A shall be applied, with the following modifications given in this annex.

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



Key

1	Calibration panel or test specimen
2	Baffle
$\theta_{s,ca}$	Average surface temperature of the calibration panel, in °C
θ_p	Average surface temperature of the reveal of the surround panel (top, side, bottom), in °C
θ_b	Average surface temperature of the baffle, in °C
θ_c	Average air temperature, in °C

Figure A.1 — Notation 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 °C 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 heat transfer coefficients, 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 the heat flow rate q_{ca} (see example given in Figure C.3).

A.3 Mean radiant temperature

The mean radiant temperature, θ_r in °C, of the surfaces "seen" by the surface of the test specimen (calibration panel or window) shall be calculated using one of the following equations:

— if the depth d of the surround panel reveal is ≤ 50 mm, then Equation (A.2) is used:

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

— if $|\theta_b - \theta_p| \leq 5$ K then Equation (A.3) is used:

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

— 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):

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

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

where

σ is the Stefan-Boltzmann constant, $\sigma = 5{,}67 \times 10^{-8}$ 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} and 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} and α_{cp}, are calculated ignoring second reflections, using Equations (A.8) and (A.9):

$$\alpha_{cb} \cong \varepsilon_c \varepsilon_b [f_{cb} + (1 - \varepsilon_p) f_{cp} \ f_{pb}] \tag{A.8}$$

$$\alpha_{cp} \cong \varepsilon_c \varepsilon_p [f_{cp} + (1 - \varepsilon_b) f_{cb} f_{bp} + (1 - \varepsilon_b) f_{cb} f_{pp}] \tag{A.9}$$

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 from calibration panel to baffle;

cp from calibration panel to surround panel reveal;

pb from surround panel reveal to baffle;

bp from baffle to surround panel reveal;

pp from surround panel reveal to surround panel reveal.

View factors depending on the depth of surround panel reveal 'd' for the standardised test aperture are given in the 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):

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

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

Table A.1 — View factors for 1230 mm ×1480 mm aperture

	Reveal depth d in mm				
	0	50	100	150	200
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] $f_{cp} = f_{bp} = 1 - f_{cb}$ (A.11)

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

Table A.2 — View factors for 1200 × 1200 mm aperture

	Reveal depth d in mm				
	0	50	100	150	200
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] $f_{cp} = f_{bp} = 1 - f_{cb}$ (A.11)

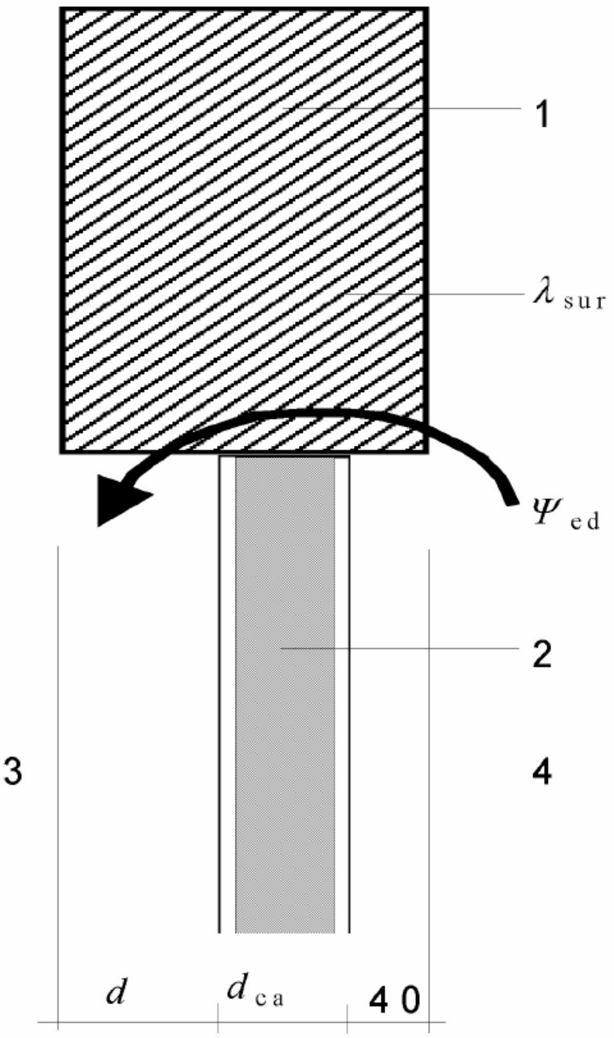
[b] $f_{pb} = \frac{(1 - f_{pp})}{2}$ (A.12)

For other geometries a detailed radiation heat exchange calculation procedure shall be used.

Annex B
(normative)

Linear thermal transmittance of the edge zone

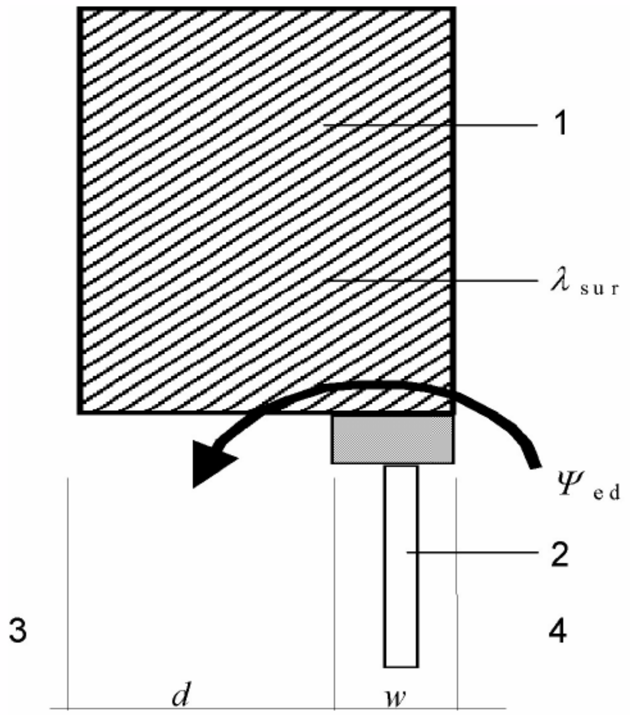
Dimensions in millimetres



Key

1 Surround panel
2 Calibration panel
3 Cold side
4 Warm side

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



Key
1 Surround panel
2 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

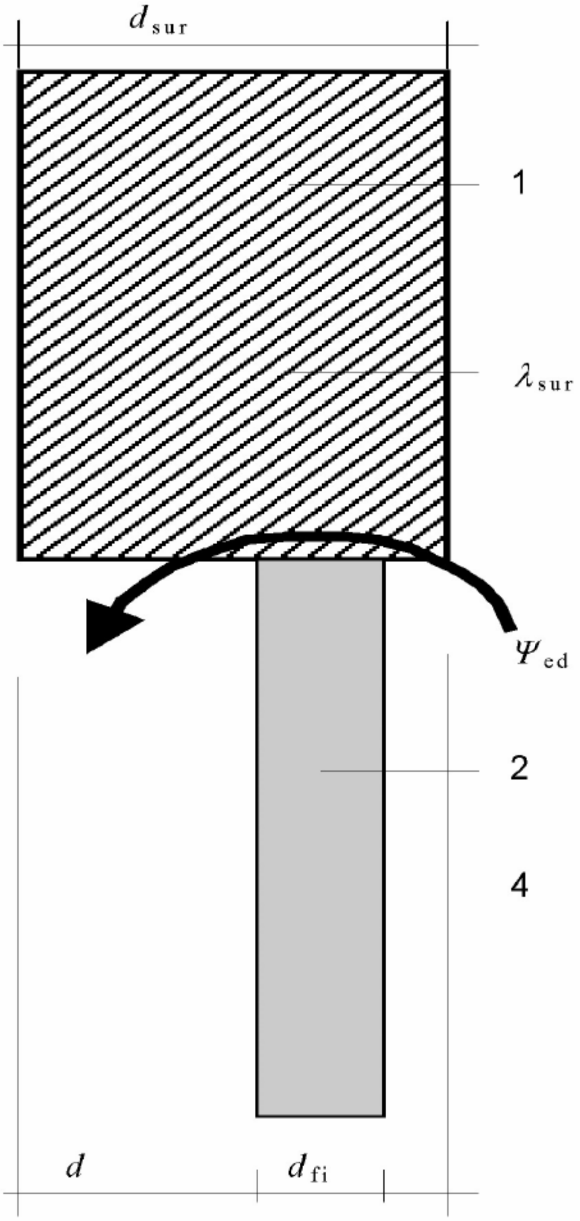
	Ψ_{ed} for d_{ca} = 20 mm W/(m·K)			Ψ_{ed} for d_{ca} = 60 mm W/(m·K)			Ψ_{ed} for d_{ca} = 100 mm W/(m·K)		
d	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)
mm	0,030	0,035	0,040	0,030	0,035	0,040	0,030	0,035	0,040
0	0,0109	0,0125	0,0140	0,0044	0,0050	0,0057	0,0023	0,0027	0,0031
20	0,0085	0,0098	0,0110	0,0041	0,0048	0,0054	0,0024	0,0028	0,0032
40	0,0099	0,0113	0,0127	0,0050	0,0058	0,0065	0,0030	0,0035	0,0040
60	0,0118	0,0135	0,0152	0,0063	0,0072	0,0082	0,0039	0,0046	0,0052
80	0,0138	0,0159	0,0178	0,0077	0,0088	0,0100	0,0050	0,0057	0,0065
100	0,0157	0,0181	0,0204	0,0090	0,0104	0,0118	0,0060	0,0070	0,0079
120	0,0176	0,0202	0,0228	0,0104	0,0120	0,0136	0,0071	0,0082	0,0093
140	0,0193	0,0222	0,0250	0,0117	0,0135	0,0153	0,0081	0,0094	0,0107
160	0,0209	0,0240	0,0271	0,0130	0,0150	0,0170	0,0091	0,0106	0,0120
180	0,0223	0,0257	0,0287	0,0142	0,0164	0,0185	0,0101	0,0117	0,0133
200	0,0237	0,0273	0,0308	0,0153	0,0177	0,0200	0,0111	0,0128	0,0145

NOTE Ψ- values for intermediate λ_{sur} , d_{ca} and d values are obtained by linear interpolation.

Table B.2 — Linear thermal transmittance for test specimen

		Ψ_{ed} W/(m·K)					Ψ_{ed} W/(m·K)		
w	d	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	w	d	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)
mm	mm	0,030	0,035	0,040	mm	mm	0,030	0,035	0,040
40	60	0,0112	0,0126	0,0139	100	40	0,0029	0,0033	0,0036
	80	0,0142	0,0160	0,0177		80	0,0063	0,0071	0,0079
	120	0,0189	0,0214	0,0238		120	0,0093	0,0106	0,0118
	160	0,0230	0,0262	0,0292		160	0,0120	0,0138	0,0155
	200	0,0263	0,0299	0,0335		200	0,0144	0,0166	0,0186
50	50	0,0079	0,0088	0,0097	110	40	0,0026	0,0029	0,0032
	80	0,0119	0,0135	0,0150		80	0,0057	0,0064	0,0072
	120	0,0163	0,0185	0,0206		120	0,0085	0,0097	0,0109
	160	0,0201	0,0229	0,0256		160	0,0111	0,0127	0,0143
	200	0,0232	0,0265	0,0297		200	0,0134	0,0153	0,0173
60	40	0,0053	0,0059	0,0065	120	40	0,0023	0,0026	0,0028
	80	0,0103	0,0116	0,0129		80	0,0051	0,0058	0,0065
	120	0,0144	0,0164	0,0183		120	0,0078	0,0089	0,0100
	160	0,0178	0,0204	0,0228		160	0,0102	0,0117	0,0132
	200	0,0208	0,0238	0,0267		200	0,0124	0,0143	0,0161
70	30	0,0033	0,0036	0,0039	130	40	0,0021	0,0023	0,0026
	60	0,0068	0,0076	0,0084		80	0,0047	0,0053	0,0060
	120	0,0126	0,0144	0,0161		120	0,0072	0,0082	0,0092
	160	0,0160	0,0183	0,0205		160	0,0095	0,0109	0,0123
	200	0,0188	0,0215	0,0241		200	0,0116	0,0133	0,0150
80	20	0,0018	0,0020	0,0021	140	40	0,0019	0,0021	0,0023
	40	0,0038	0,0043	0,0047		80	0,0043	0,0049	0,0055
	80	0,0079	0,0089	0,0099		120	0,0067	0,0076	0,0086
	160	0,0113	0,0129	0,0185		160	0,0089	0,0102	0,0114
	200	0,0171	0,0196	0,0220		200	0,0108	0,0125	0,0140
90	10	0,0008	0,0009	0,0009	150	40	0,0017	0,0019	0,0021
	30	0,0024	0,0027	0,0029		80	0,0040	0,0045	0,0050
	60	0,0052	0,0059	0,0065		120	0,0062	0,0071	0,0079
	120	0,0102	0,0116	0,0130		160	0,0083	0,0095	0,0107
	200	0,0157	0,0180	0,0202		200	0,0102	0,0117	0,0132

NOTE: Ψ- values for intermediate λ_{sur} can be obtained by linear interpolation.
If w > 150 mm , then Ψ_{ed} is very small and can be neglected (Ψ = 0).



Key

1 Surround panel
2 Infill insulation with thickness d_{fi}
3 Cold side
4 Warm side

Figure B.3 — Linear thermal transmittance of the edge zone

Table B.3 — Linear thermal transmittance for the infill insulation with conductivity values λ_{fi} between 0,030 W/(m·K) to 0,035 W/(m·K)

		Ψ_{ed} for d_{fi} = 20mm W/(m·K)				Ψ_{ed} for d_{fi} = 30mm W/(m·K)				Ψ_{ed} for d_{fi} = 40mm W/(m·K)		
d	d_{sur}	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	d	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	d	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)	λ_{sur} W/(m·K)
mm	mm	0,030	0,035	0,040	mm	0,030	0,035	0,040	mm	0,030	0,035	0,040
0	100	0,0185	0,0211	0,0235	0	0,0131	0,0150	0,0165	0	0,0092	0,0105	0,0118
20		0,0106	0,0122	0,0137	20	0,0073	0,0083	0,0091	20	0,0049	0,0056	0,0063
40		0,0090	0,0103	0,0115	40	0,0065	0,0075	0,0081	40	0,0050	0,0057	0,0065
60		0,0111	0,0126	0,0142	60	0,0097	0,0111	0,0121	60	0,0096	0,0108	0,0121
80		0,0193	0,0218	0,0242	70	0,0137	0,0155	0,0170	–	–	–	–
0	120	0,0216	0,0246	0,0275	0	0,0161	0,0184	0,0203	0	0,0120	0,0138	0,0155
20		0,0133	0,0152	0,0171	20	0,0097	0,0111	0,0123	20	0,0071	0,0081	0,0092
40		0,0107	0,0123	0,0138	40	0,0079	0,0090	0,0099	40	0,0059	0,0067	0,0076
60		0,0109	0,0125	0,0140	60	0,0087	0,0099	0,0109	60	0,0073	0,0084	0,0095
80		0,0138	0,0158	0,0178	80	0,0125	0,0143	0,0158	80	0,0137	0,0142	0,0158
100		0,0225	0,0255	0,0283	90	0,0167	0,0190	0,0210	–	–	–	–
0	140	0,0242	0,0277	0,0309	0	0,0187	0,0213	0,0237	0	0,0145	0,0167	0,0187
20		0,0157	0,0180	0,0202	20	0,0120	0,0138	0,0152	20	0,0092	0,0106	0,0119
40		0,0126	0,0145	0,0162	40	0,0095	0,0110	0,0121	40	0,0073	0,0084	0,0095
60		0,0118	0,0135	0,0152	60	0,0092	0,0106	0,0116	60	0,0074	0,0085	0,0096
80		0,0129	0,0148	0,0166	80	0,0107	0,0123	0,0136	80	0,0095	0,0109	0,0123
100		0,0163	0,0187	0,0210	100	0,0151	0,0173	0,0191	100	0,0151	0,0171	0,0192
120		0,0252	0,0286	0,0319	110	0,0194	0,0221	0,0244	–	–	–	–
0	160	0,0265	0,0303	0,0340	0	0,0209	0,0240	0,0267	0	0,0168	0,0192	0,0216
20		0,0179	0,0205	0,0230	20	0,0141	0,0162	0,0179	20	0,0112	0,0129	0,0145
40		0,0145	0,0165	0,0186	40	0,0113	0,0129	0,0143	40	0,0089	0,0102	0,0115
60		0,0131	0,0150	0,0168	60	0,0103	0,0118	0,0130	60	0,0082	0,0094	0,0107
80		0,0132	0,0151	0,0170	80	0,0107	0,0123	0,0136	80	0,0090	0,0104	0,0117
100		0,0148	0,0170	0,0191	100	0,0127	0,0146	0,0162	100	0,0116	0,0133	0,0150
120		0,0185	0,0213	0,0239	120	0,0173	0,0199	0,0221	120	0,0173	0,0198	0,0222
140		0,0276	0,0314	0,0350	130	0,0217	0,0248	0,0275	–	–	–	–
0	180	0,0286	0,0327	0,0367	0	0,0230	0,0264	0,0293	0	0,0188	0,0216	0,0243
20		0,0198	0,0227	0,0256	20	0,0160	0,0184	0,0205	20	0,0130	0,0150	0,0169
40		0,0162	0,0186	0,0209	40	0,0129	0,0149	0,0165	40	0,0104	0,0120	0,0135
60		0,0145	0,0166	0,0187	60	0,0115	0,0132	0,0146	60	0,0093	0,0107	0,0121
80		0,0140	0,0161	0,0180	80	0,0113	0,0130	0,0144	80	0,0094	0,0108	0,0122
100		0,0147	0,0168	0,0189	100	0,0123	0,0141	0,0156	100	0,0106	0,0123	0,0138
120		0,0166	0,0191	0,0215	120	0,0146	0,0168	0,0187	120	0,0135	0,0155	0,0175
140		0,0206	0,0236	0,0266	140	0,0194	0,0223	0,0248	140	0,0194	0,0222	0,0249
160		0,0297	0,0339	0,0378	150	0,0238	0,0272	0,0303	–	–	–	–
0	200	0,0305	0,0349	0,0391	0	0,0249	0,0285	0,0317	0	0,0206	0,0237	0,0266
20		0,0216	0,0248	0,0279	20	0,0178	0,0204	0,0227	20	0,0147	0,0170	0,0191
40		0,8750	0,0205	0,0230	40	0,0145	0,0167	0,0185	40	0,0119	0,0137	0,0155
60		0,0159	0,0182	0,0204	60	0,0128	0,0147	0,0163	60	0,0105	0,0121	0,0136
80		0,0153	0,0172	0,0193	80	0,0122	0,0140	0,0155	80	0,0101	0,0093	0,0131
100		0,0151	0,0173	0,0194	100	0,0125	0,0144	0,0159	100	0,0106	0,0123	0,0138
120		0,0161	0,0185	0,0208	120	0,0138	0,0159	0,0176	120	0,0122	0,0141	0,0159
140		0,0183	0,0210	0,0237	140	0,0163	0,0188	0,0209	140	0,0152	0,0175	0,0198
160		0,0224	0,0257	0,0290	160	0,0213	0,0244	0,0272	160	0,0213	0,0243	0,0273
180		0,0316	0,0361	0,0403	170	0,0257	0,0294	0,0330	–	–	–	–

(*continued*)

Table B.3 (*continued*)

0	220	0,0322	0,0369	0,0414	0	0,0266	0,0305	0,0340	0	0,0223	0,0256	0,0288
20		0,0233	0,0267	0,0301	20	0,0194	0,0223	0,0249	20	0,0163	0,0188	0,0212
40		0,0194	0,0223	0,0250	40	0,0160	0,0184	0,0205	40	0,0134	0,0154	0,0174
60		0,0172	0,0197	0,0222	60	0,0141	0,0162	0,0180	60	0,0117	0,0135	0,0152
80		0,0161	0,0185	0,0207	80	0,0132	0,0152	0,0168	80	0,0110	0,0127	0,0143
100		0,0158	0,0181	0,0203	100	0,0131	0,0150	0,0166	100	0,0111	0,0127	0,0144
120		0,0162	0,0186	0,0209	120	0,0137	0,0158	0,0175	120	0,0119	0,0137	0,0155
140		0,0175	0,0201	0,0226	140	0,0141	0,0175	0,0195	140	0,0137	0,0158	0,0178
160		0,0199	0,0229	0,0257	160	0,0179	0,0207	0,0230	160	0,0169	0,0194	0,0219
180		0,0241	0,0277	0,0312	180	0,0230	0,0264	0,0294	180	0,0230	0,0263	0,0296
200		0,0334	0,0381	0,0425	190	0,0275	0,0314	0,0350	–	–	–	–
0	240	0,0338	0,0387	0,0434	0	0,0281	0,0323	0,0360	0	0,0238	0,0274	0,0309
20		0,0248	0,0285	0,0321	20	0,0209	0,0241	0,0268	20	0,0178	0,0205	0,0232
40		0,0208	0,0239	0,0269	40	0,0174	0,0200	0,0223	40	0,0147	0,0170	0,0191
60		0,0185	0,0213	0,0239	60	0,0154	0,0177	0,0196	60	0,0129	0,0149	0,0168
80		0,0172	0,0197	0,0222	80	0,0142	0,0164	0,0181	80	0,0120	0,0138	0,0156
100		0,0166	0,0191	0,0214	100	0,0138	0,0159	0,0176	100	0,0117	0,0135	0,0152
120		0,0167	0,0191	0,0215	120	0,0140	0,0161	0,0179	120	0,0121	0,0139	0,0157
140		0,0174	0,0199	0,0225	140	0,0149	0,0171	0,0190	140	0,0131	0,0151	0,0171
160		0,0188	0,0217	0,0244	160	0,0166	0,0183	0,0213	160	0,0151	0,0174	0,0196
180		0,0213	0,0245	0,0277	180	0,0194	0,0224	0,0250	180	0,0183	0,0211	0,0239
200		0,0256	0,0295	0,0332	200	0,0245	0,0282	0,0315	200	0,0245	0,0281	0,0316
220		0,0350	0,0399	0,0447	210	0,0290	0,0332	0,0371	–	–	–	–
0	260	0,0352	0,0404	0,0453	0	0,0295	0,0339	0,0379	0	0,0253	0,0290	0,0327
20		0,0262	0,0301	0,0339	20	0,0223	0,0257	0,0287	20	0,0192	0,0221	0,0250
40		0,0221	0,0255	0,0287	40	0,0187	0,0215	0,0240	40	0,0160	0,0185	0,0209
60		0,0197	0,0227	0,0255	60	0,0166	0,0191	0,0212	60	0,0141	0,0162	0,0183
80		0,0183	0,0210	0,0236	80	0,0153	0,0176	0,0195	80	0,0130	0,0149	0,0169
100		0,0175	0,0201	0,0226	100	0,0146	0,0168	0,0187	100	0,0125	0,0143	0,0162
120		0,0173	0,0198	0,0223	120	0,0145	0,0167	0,0186	120	0,0125	0,0144	0,0163
140		0,0176	0,0202	0,0227	140	0,0150	0,0173	0,0192	140	0,0131	0,0151	0,0171
160		0,0185	0,0213	0,0239	160	0,0161	0,0185	0,0206	160	0,0143	0,0165	0,0187
180		0,0201	0,0231	0,0261	180	0,0179	0,0206	0,0230	180	0,0164	0,0189	0,0214
200		0,0227	0,0261	0,0295	200	0,0208	0,0240	0,0268	200	0,0197	0,0227	0,0257
220		0,0271	0,0311	0,0351	220	0,0259	0,0299	0,0334	220	0,0261	0,0299	0,0336
240		0,0364	0,0416	0,0467	230	0,0305	0,0349	0,0390	–	–	–	–

(*continued*)

Table B.3 (*continued*)

0	280	0,0366	0,0419	0,0471	0	0,0309	0,0355	0,0397	0	0,0266	0,0306	0,0345
20		0,0275	0,0316	0,0357	20	0,0236	0,0271	0,0304	20	0,0205	0,0236	0,0267
40		0,0234	0,0269	0,0303	40	0,0199	0,0230	0,0257	40	0,0172	0,0199	0,0225
60		0,0209	0,0240	0,0271	60	0,0177	0,0204	0,0227	60	0,0152	0,0175	0,0201
80		0,0193	0,0222	0,0250	80	0,0163	0,0188	0,0209	80	0,0140	0,0161	0,0182
100		0,0184	0,0211	0,0238	100	0,0155	0,0178	0,0198	100	0,0133	0,0153	0,0173
120		0,0180	0,0207	0,0233	120	0,0152	0,0175	0,0194	120	0,0131	0,0151	0,0170
140		0,0180	0,0207	0,0233	140	0,0153	0,0177	0,0196	140	0,0134	0,0154	0,0174
160		0,0185	0,0213	0,0240	160	0,0160	0,0184	0,0205	160	0,0141	0,0163	0,0184
180		0,0196	0,0225	0,0254	180	0,0172	0,0198	0,0221	180	0,0155	0,0179	0,0202
200		0,0213	0,0245	0,0277	200	0,0191	0,0220	0,0246	200	0,0176	0,0203	0,0230
220		0,0240	0,0276	0,0311	220	0,0221	0,0255	0,0285	220	0,0210	0,0243	0,0274
240		0,0284	0,0327	0,0369	240	0,0273	0,0314	0,0351	240	0,0273	0,0314	0,0353
260		0,0378	0,0432	0,0485	250	0,0318	0,0365	0,0410	–	–	–	–
0	300	0,0378	0,0433	0,0487	0	0,0321	0,0369	0,0413	0	0,0278	0,0320	0,0361
20		0,0287	0,0331	0,0373	20	0,0248	0,0285	0,0319	20	0,0217	0,0250	0,0282
40		0,0246	0,0283	0,0319	40	0,0211	0,0243	0,0272	40	0,0184	0,0212	0,0239
60		0,0221	0,0253	0,0285	60	0,0188	0,0217	0,0241	60	0,0163	0,0188	0,0212
80		0,0204	0,0234	0,0263	80	0,0173	0,0199	0,0222	80	0,0149	0,0172	0,0194
100		0,0193	0,0222	0,0250	100	0,0164	0,0188	0,0209	100	0,0141	0,0163	0,0184
120		0,0187	0,0215	0,0242	120	0,0159	0,0183	0,0203	120	0,0137	0,0158	0,0179
140		0,0186	0,0213	0,0240	140	0,0158	0,0182	0,0203	140	0,0138	0,0159	0,0179
160		0,0188	0,0216	0,0243	160	0,0162	0,0385	0,0207	160	0,0142	0,0164	0,0185
180		0,0195	0,0224	0,0252	180	0,0170	0,0195	0,0217	180	0,0151	0,0174	0,0197
200		0,0207	0,0237	0,0268	200	0,0183	0,0210	0,0235	200	0,0166	0,0191	0,0216
220		0,0225	0,0258	0,0291	220	0,0203	0,0233	0,0261	220	0,0188	0,0217	0,0245
240		0,0252	0,0290	0,0327	240	0,0233	0,0269	0,0275	240	0,0223	0,0257	0,0290
260		0,0296	0,0341	0,0385	260	0,0285	0,0329	0,0368	260	0,0286	0,0328	0,0369
280		0,0390	0,0447	0,0501	270	0,0331	0,0378	0,0425	–	–	–	–

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

Annex C
(informative)

Example of calibration test and measurement of frame specimen

C.1 Calibration test with panel size 1,23 m × 1,48 m

Two calibration panels with total thermal resistance approximately 0,3 $m^2 \cdot K/W$ and 1,4 $m^2 \cdot K/W$ and total thickness 17 mm and 56 mm respectively are used. The panels are built with core material of expanded polystyrene and covered on both sides with 4 mm float glass according to EN ISO 12567-1:2000, annex C and have dimensions 1,23 m × 1,48 m. The calibration panel has been installed in a surround panel made of polystyrene with a thickness of 220 mm.

The basic data for the polystyrene core and surround panel material have been measured in a hot plate apparatus according to ISO 8302, *Thermal insulation – Determination of steady-state thermal resistance and related properties – Guarded hot plate apparatus.* The measured data are:

Panel 1 (d = 17 mm) $R_{ca} = 0{,}30009 - 0{,}00052245\ \theta_{me}$

Panel 2 (d = 56 mm) $R_{ca} = 1{,}490001 - 0{,}0081521\ \theta_{me}$

Surround panel (d = 220 mm) $\lambda_{sur} = 0{,}0301625 + 0{,}0000525\ \theta_{me}$

Where θ_{me} is the mean temperature in °C.

The calibration panel data are given in Table C.1.

Table C.1 — Calibration panel

Measured values			Panel 1			Panel 2		
d_{ca}	overall thickness	m	0,017			0,056		
A_{ca}	area of panel	m²	1,82			1,82		
A_{sur}	area of surround panel	m²	2,61			2,61		
$A_{t,hb}$	hot box metering area	m²	4,43			4,43		
L	perimeter length	m	5,42			5,42		
Test number			2	1[a]	3	4	5	6
Cold temperatures								
θ_{ce}	air	°C	- 3,92	0,96	9,94	- 7,28	2,01	7,86
$\theta_{se,b}$	baffle	°C	- 3,67	1,05	9,97	- 7,24	2,04	7,85
$\theta_{se,ca}$	calibration panel	°C	- 1,24	3,09	11,21	- 6,29	2,79	8,39
$\theta_{se,p}$	reveal panel	°C	- 3,56	1,03	9,84	- 7,22	2,02	7,82
$\theta_{se,sur}$	surround panel	°C	- 3,81	0,94	9,85	- 7,41	1,95	7,74
Warm temperatures								
θ_{ci}	air	°C	22,42	22,40	22,68	23,15	23,20	23,23
$\theta_{si,b}$	baffle	°C	24,54	24,15	23,72	23,94	23,75	23,69
$\theta_{si,ca}$	calibration panel	°C	16,30	17,31	19,46	20,68	21,45	21,90
$\theta_{si,p}$	reveal panel	°C	20,49	20,54	21,60	21,77	21,82	22,17
$\theta_{si,sur}$	surround panel	°C	20,72	21,03	21,71	22,03	22,40	22,43
Φ_{in}	input power	W	120,11	97,34	57,45	46,55	32,95	24,17
v_i	air flow warm side, down	m/s	< 0,2	< 0,2	< 0,2	< 0,2	< 0,2	< 0,2
v_e	air flow cold side, down	m/s	~1,5	~1,5	~1,5	~1,5	~1,5	~1,5

[a] That test is used to fix the fan setting on the cold side.

Table C.2 — Linear thermal transmittance and view factors of the calibration panel

Values resulting from mounting instructions			Remarks	Panel 1	Panel 2
Total thickness of the calibration panel		mm	–	17	56
Total thickness of the surround panel		mm	–	220	220
Surround panel reveal depth – warm side		mm	–	40	40
Surround panel reveal depth – cold side		mm	–	163	~124
Ψ_{ed} for λ = 0,030 W/(m·K)		W/(m·K)	Table B.1	0,0211	0,0107
Warm side	view factors	f_{cbi}	Table A.2	0,944	0,944
		f_{ppi}	Table A.2	0,047	0,047
		f_{cpi}	Equation (A.11)	0,056	0,056
		f_{bpi}	Equation (A.11)	0,056	0,056
		f_{pbi}	Equation (A.12)	0,476	0,476
	radiant factors	α_{cbi}	Equation (A.8)	0,750	0,750
		α_{cpi}	Equation (A.9)	0,049	0,049
Cold side	view factors	f_{cbe}	Table A.2	0,801	0,845
		f_{ppe}	Table A.2	0,147	0,118
		f_{cpe}	Equation (A.11)	0,199	0,155
		f_{bpe}	Equation (A.11)	0,199	0,155
		f_{pbe}	Equation (A.12)	0,426	0,441
	radiant factors	α_{cbe}	Equation (A.8)	0,642	0,675
		α_{cpe}	Equation (A.9)	0,174	0,136

NOTE The radiant factors have been calculated with the following emissivities: ε_{ca} = 0,84; ε_{p} = 0,92, ε_{b} = 0,95.

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

Data element		Remarks	Panel 2		
$\Delta\theta_c$	K	–	30,43	21,19	15,37
$\Delta\theta_{s,sur}$	K	–	29,44	20,45	14,69
$\theta_{me,sur}$	°C	–	7,31	12,18	15,09
Φ_{in}	W	–	46,55	32,95	24,17
Φ_{ca}	W	Equation (9)	34,31	24,41	18,00
Φ_{ed}	W	Equation (10)	1,76	1,23	0,89
Φ_{in} - Φ_{ca} - Φ_{ed}	W	–	10,48	7,31	5,28
R_{sur}	$m^2 \cdot K/W$	Equation (8)	7,33	7,30	7,26
Optional check with data of hot plate measurement					
$\theta_{me,sur}$	°C	–	7,31	12,18	15,09
λ_{sur}	W/(m·K)	linear regression	0,0305	0,0308	0,0310
R_{sur}	$m^2 \cdot K/W$	d/λ_{sur}	7,21	7,14	7,10
$\Delta R_{sur}/R_{sur}$	%	relative difference	-1,8	-2,2	-2,2

Table C.4 — Calculation of surface resistance and convective fraction F_c

Data element		Remarks	Panel 1			Panel 2		
$\theta_{me,ca}$	°C	–	7,53	10,20	15,33	7,20	12,12	15,15
$\Delta\theta_{s,ca}$	K	–	17,54	14,22	8,25	26,97	18,66	13,51
R_{ca}	$m^2 \cdot K/W$	Equation (3)	0,296	0,295	0,292	1,431	1,392	1,366
q_{ca}	W/m^2	Equation (2)	59,26	48,20	28,25	18,85	13,41	9,89
$h_{cb,i}$	$W/(m^2 \cdot K)$	Equation (A.6)	5,739	5,757	5,807	5,850	5,867	5,879
$h_{cb,e}$	$W/(m^2 \cdot K)$	Equation (A.6)	4,499	4,728	5,181	4,287	4,746	5,047
$h_{cp,i}$	$W/(m^2 \cdot K)$	Equation (A.7)	5,621	5,651	5,745	5,785	5,810	5,834
$h_{cp,e}$	$W/(m^2 \cdot K)$	Equation (A.7)	4,502	4,728	5,177	4,288	4,745	5,046
$h_{r,i}$	$W/(m^2 \cdot K)$	Equation (A.5)	4,589	4,604	4,646	4,680	4,694	4,704
$h_{r,e}$	$W/(m^2 \cdot K)$	Equation (A.5)	3,628	3,813	4,177	3,450	3,819	4,061
$\theta_{r,i}$	°C	Equation (A.3)	- 24,54	24,15	23,72	23,94	23,75	23,69
$\theta_{r,e}$	°C	Equation (A.2)	- 3,65	1,05	9,95	-7,24	2,03	7,84
$h_{c,i}$	$W/(m^2 \cdot K)$	Equation (A.10)	3,17	2,91	2,21	1,69	1,45	0,91
$h_{c,e}$	$W/(m^2 \cdot K)$	Equation (A.10)	18,05	18,02	17,10	16,28	13,32	14,05
$F_{c,i}$	-	Equation (6)	0,408	0,387	0,322	0,265	0,236	0,161
$F_{c,e}$	-	Equation (6)	0,833	0,825	0,804	0,825	0,777	0,776
$\theta_{ni,ca}$	°C	Equation (7)	23,67	23,47	23,38	23,94	23,62	23,62
$\theta_{ne,ca}$	°C	Equation (7)	- 3,88	0,97	9,94	-7,27	2,01	7,85
$\Delta\theta_{n,ca}$	K	–	27,55	22,50	13,44	31,21	21,61	15,17
R_{si}	$m^2 \cdot K/W$	Equation (4)	0,129	0,133	0,146	0,157	0,163	0,178
R_{se}	$m^2 \cdot K/W$	Equation (5)	0,046	0,046	0,047	0,051	0,058	0,055
$R_{s,t}$	$m^2 \cdot K/W$	Equation (1)	0,175	0,179	0,193	0,208	0,221	0,234

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

thermal resistance of the surround panel: $R_{sur} = 7{,}3970 - 0{,}0087\ \theta_{me,sur}$

convective fraction: $F_{c,i} = 0{,}1626 + 0{,}0047\ q_{sp}$

$F_{c,e} = 0{,}7738 + 0{,}0011\ q_{sp}$

Total surface resistance $R_{s,t} = 0{,}3378\ q_{sp}^{-0{,}16}$

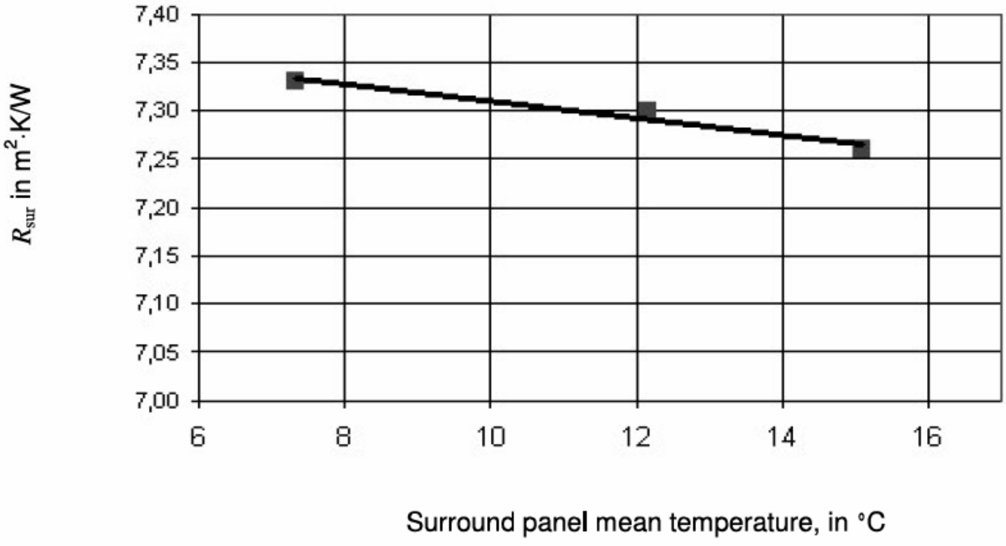


Figure C.1 — Thermal resistance of the surround panel

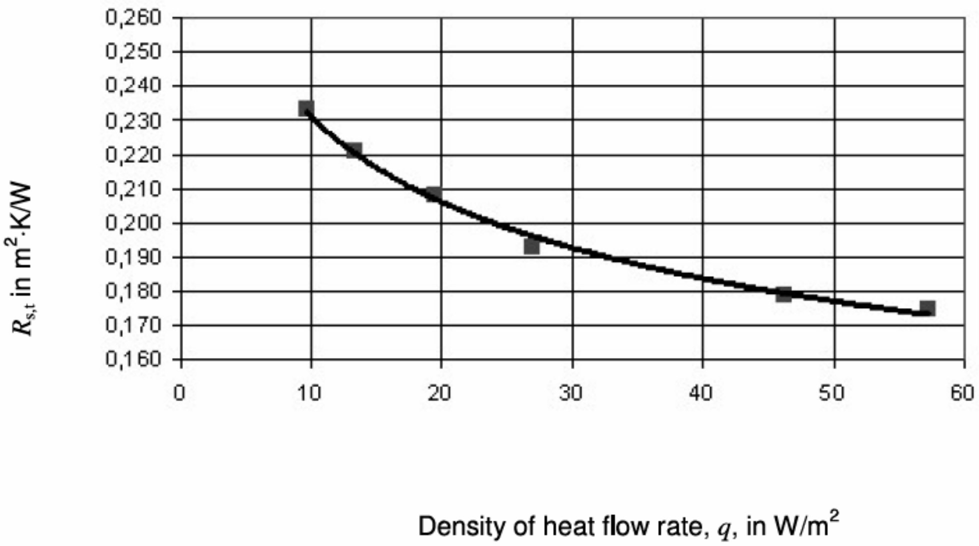


Figure C.2 — Total surface resistance

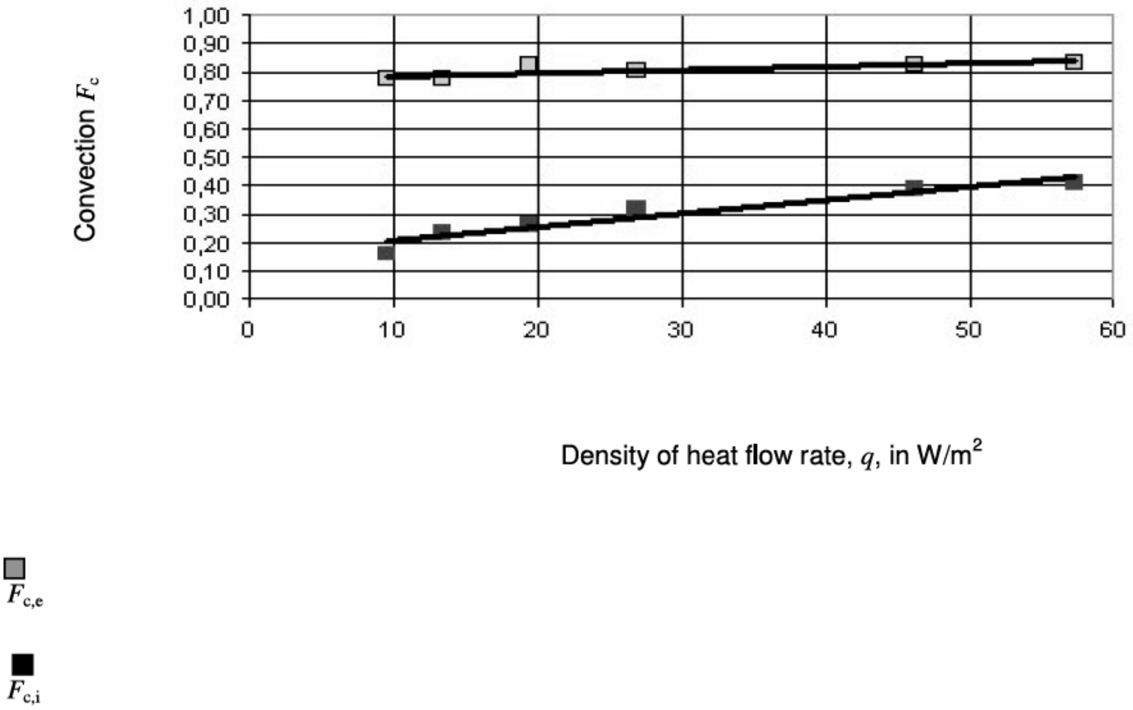


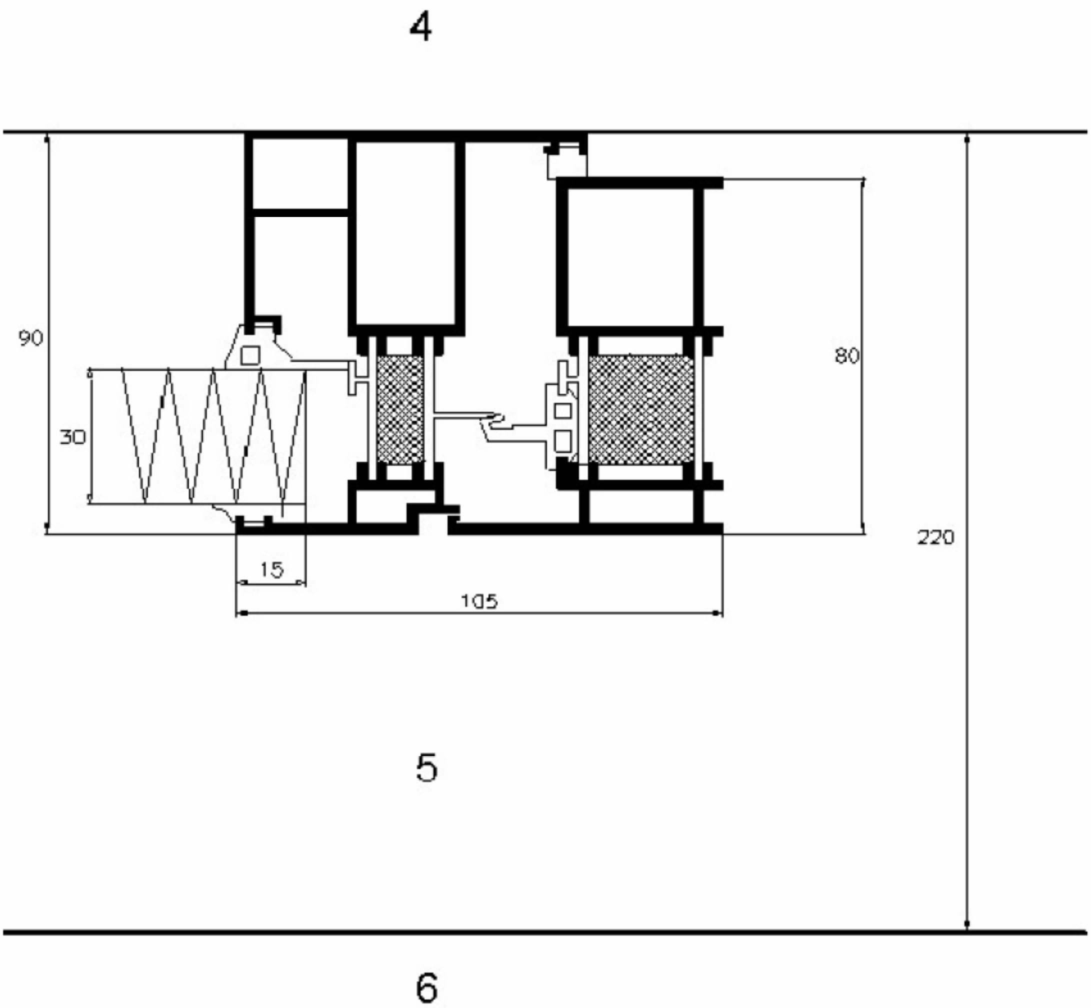
Figure C.3 — Convective fractions – cold side and warm side

C.2 Frame specimen measurement

Description of the specimen

Tested object:		thermally broken metal profile
Thermal break:		polyamide glass fibre reinforced
Number of identical test specimens:		4
Height of each test specimen:		1480 mm
Width of each specimen:	on the warm side	104 mm
	on the cold side	105 mm
Total thickness of each specimen:		90 mm
Projected frame area		0,6216 m^2
Developed frame area:	on the warm side:	0,9886 m^2
	on the cold side:	0,6808 m^2
Seals:		2 lip seals of EPDM

Dimensions in millimetres



Key

1 Insulating material
2 Thermal break
3 Filling panel, λ = 0,0302 W/(m·K)
4 Warm side
5 Surround panel
6 Cold side

Figure C.4 — Cross section of the specimen

Results of test specimen measurements

The quantities used for the determination of the U-value are listed below:

Areas:	area of hot box aperture	$A_{t, hb}$ = 2,08 m × 2,13 m	=	4,43 m^2
	area of calibration panel aperture	A_{ca} = 1,23 m × 1,48 m in this case, A_{ca} corresponds to A_t	=	1,82 m^2
	projected frame area	A_f = 4 × 1,48 m × 0,105 m	=	0,6216 m^2
	infill insulation area	A_{fi} = $A - A_f$	=	1,198 m^2
	perimeter length	L_{ed} =		5,42 m

Hemispherical emissivities:

baffle	ε_b	= 0,89
sample	ε_{sp}	= 0,89
calibration panel	ε_{ca}	= 0,89
surround panel	ε_{sur}	= 0,89

Infill insulation data:

thickness	d_{fi}	= 30,0 mm

Sequence of calculations to determine the U-value (see Tables C.5 to C.7):

q_t = 26,73 W/m^2 from measurement

$F_{c,i}$ (q_{ca}) = 0,288 linear regression of calibration panel data (see Figure C.3)

$F_{c,e}$ (q_{ca}) = 0,803 linear regression of calibration panel data (see Figure C.3)

$\theta_{c,i}$ = 22,46 °C $\theta_{r,i} = \theta_{b,i}$ = 23,10 °C

$\theta_{c,e}$ = 1,08 °C $\theta_{r,e} = \theta_{b,e}$ = 1,03 °C

$$\theta_{ni} = F_{c,i} \cdot \theta_{c,i} + (1 - F_{c,i})\,\theta_{r,i}$$

$$= 0{,}288 \times 22{,}46 + (1 - 0{,}288) \times 23{,}10 = 22{,}92\ °C \qquad (7)$$

$$\theta_{ne} = F_{c,e} \cdot \theta_{c,e} + (1 - F_{c,e})\theta_{r,e}$$

$$= 0{,}803 \times 1{,}08 + (1 - 0{,}803) \times 1{,}03 = 1{,}07\ °C \qquad (7)$$

$R_{s,t}$ (q_t) = 0,200 m^2·K/W

$$R_{sur} = \frac{A_{sur} \Delta\theta_{s,sur}}{\Phi_{in} - \Phi_{ca} - \Phi_{ed}} = \frac{2{,}61 \times 20{,}09}{97{,}34 - 87{,}74 - 2{,}42} = 7{,}30\ \text{m}^2\cdot\text{K/W} \qquad (8)$$

$$\Phi_{ca} = A_{ca}\, q_{ca} = 1{,}82 \times 48{,}20 = 87{,}74\ \text{W} \qquad (9)$$

Measurement procedure for specimen

$$\Phi_{ed} = L_{ed}\,\Psi_{ed}\,\Delta\theta_c = 5{,}42 \times 0{,}0140 \times 21{,}38 = 1{,}62 \tag{10}$$

$$q_t = \frac{\Phi_{in} - \Phi_{sur} - \Phi_{ed}}{A_t} = \frac{57{,}57 - 7{,}29 - 1{,}62}{1{,}23 \times 1{,}48} = 26{,}73 \text{ W/m}^2 \tag{11}$$

$$\Phi_{sur} = \frac{A_{sur}\,\Delta\theta_{s,sur}}{R_{sur}} = \frac{2{,}61 \times 20{,}39}{7{,}30} = 7{,}29 \text{ W} \tag{12}$$

$$U_{m,t} = \frac{q_t}{\Delta\theta_n} = \frac{26{,}73}{21{,}85} = 1{,}22 \text{ W/m}^2\text{K} \tag{13}$$

$$U_f = \frac{U_{m,t}\,A_t\,\Delta\theta_n - \Lambda_{fi}\,\Delta\theta_{s,fi}\,A_{fi}}{A_f\;\Delta\theta_n} = \frac{1{,}22 \times 1{,}82 \times 21{,}85 - 1{,}01 \times 15{,}82 \times 1{,}198}{0{,}6216 \times 21{,}85} = 2{,}16 \text{ W/(m}^2\cdot\text{K)} \tag{14}$$

Table C.5 — Frame data

Data element			Value
w	Frame width	in m	0,105
d_{sur}	Surround panel thickness	in m	0,220
A_{sp}	Area of frame	in m^2	0,6216
A_{sur}	Area of surround panel	in m^2	2,61
L	Perimeter length	in m	5,42

Table C.6 — Frame measurement results

Data element			Value
Cold temperatures - measured			
θ_{ce}	(air)	in °C	1,08
$\theta_{se,b}$	(baffle)	in °C	1,03
$\theta_{se,sur}$	(surround panel)	in °C	1,27
Warm temperatures - measured			
θ_{ci}	(air)	in °C	22,46
$\theta_{si,b}$	(baffle)	in °C	23,10
$\theta_{si,sur}$	(surround panel)	in °C	21,66
Φ_{in}	(input power in hot box)	in W	57,57
v_i	(air flow warm, down)	in m/s	< 0,2
v_e	(air flow cold, up)	in m/s	~1,5

Table C.7 — Calculation of the thermal transmittance of the frame

Data element		Value	Remarks
$\theta_{me,sur}$ (mean temp. of surround panel)	in °C	11,77	–
R_{sur} (surround panel resistance)	in $m^2 \cdot K/W$	7,30	Figure C.1 / regression and Equation 8
λ_{sur} (conductivity of surround panel)	in $W/(m \cdot K)$	0,030	–
Ψ_{ed} for infill insulation 30 mm	in $W/(m \cdot K)$	0,0140	Table B.3
$\Delta\theta_{s,sur}$ (temp, difference of surround panel)	in K	20,39	–
$\Delta\theta_c$ (air temp. difference)	in K	21,38	–
Φ_{in} (input power in hot box)	in W	57,57	–
Φ_{sur} (surround panel heat flow)	in W	7,29	Equation (12)
Φ_{ed} (edge zone heat flow)	in W	1,62	Equation (10)
q_t (heat flow rate through infill insulation and frame)	in W/m^2	26,73	Equation (11)
$U_{m,t}$ (measured thermal transmittance of the infill insulation and frame)	in $W/(m^2 \cdot K)$	1,22	Equation (13)
F_{ci} (convective fraction - warm)	–	0,288	Figure C.3 / regression
F_{ce} (convective fraction - cold)	–	0,803	Figure C.3 / regression
$R_{s,t}$ (total surface resistance)	in $m^2 \cdot K/W$	0,200	Figure C.2 / regression
θ_{ri} (radiant temp.- warm)	in °C	23,10	Equation (A.2) to (A.4)
θ_{re} (radiant temp.- cold)	in °C	1,03	Equation (A.2) to (A.4)
θ_{ni} (environmental temp.- hot)	in °C	22,92	Equation (7)
θ_{ne} (environmental temp. - cold)	in °C	1,07	Equation (7)
$\Delta\theta_n$ (environmental temp. difference)	in K	21,85	–
U_f (measured)	in $W/(m^2 \cdot K)$	2,16	Equation (14)
ΔU_f (uncertainty of the measurement)	in $W/(m^2 \cdot K)$	± 0,05	–