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

Composants et parois de bâtiments — Résistance thermique et coefficient de transmission thermique — Méthode de calcul

Reference number
ISO 6946:2007(E)

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Foreword

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

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

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

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

ISO 6946 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This second edition cancels and replaces the first edition (ISO 6946:1996), which has been technically revised. It also incorporates the Amendment ISO 6946:1996/Amd.1:2003.

The following changes have been made to the first edition:

- information on the calculation of heat flow rates has been transferred from the Introduction to the note in Clause 4;
- 5.3.3 provides an amended basis for slightly ventilated air layers;
- 5.4.2 provides clarification of the applicability of Table 3;
- 5.4.3 has been completely revised;
- 6.2.1 provides a new text to allow calculation of a component that is part of a complete element; it also clarifies exceptions and the limit of applicability;
- Annex B provides additional data for other temperature differences across cavities; it also provides a correction to the formula for radiation transfer in divided airspaces;
- Annex C contains an additional shape;
- D.2 has been completely rewritten to clarify the intentions, the former Annex E having been deleted (national annexes can be attached to this International Standard giving examples in accordance with local building traditions);
- D.3 provides a revised procedure for mechanical fasteners, including recessed fasteners;
- D.4 does not apply in cooling situations.

Introduction

This International Standard provides the means (in part) to assess the contribution that building products and services make to energy conservation and to the overall energy performance of buildings.

INTERNATIONAL STANDARD **ISO 6946:2007(E)**

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

1 Scope

This International Standard provides the method of calculation of the thermal resistance and thermal transmittance of building components and building elements, excluding doors, windows and other glazed units, curtain walling, components which involve heat transfer to the ground, and components through which air is designed to permeate.

The calculation method is based on the appropriate design thermal conductivities or design thermal resistances of the materials and products for the application concerned.

The method applies to components and elements consisting of thermally homogeneous layers (which can include air layers).

This International Standard also provides an approximate method that can be used for elements containing inhomogeneous layers, including the effect of metal fasteners, by means of a correction term given in Annex D. Other cases where insulation is bridged by metal are outside the scope of this International Standard.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 7345, *Thermal insulation — Physical quantities and definitions*

ISO 10456, *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values*

ISO 13789, *Thermal performance of buildings — Transmission and ventilation heat transfer coefficients — Calculation method*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345 and ISO 10456 and the following apply.

3.1.1
building element
major part of a building such as a wall, floor or roof

3.1.2

building component

building element or a part of it

NOTE In this International Standard, the word “component” is used to indicate both element and component.

3.1.3

thermally homogeneous layer

layer of constant thickness having thermal properties which may be regarded as being uniform

3.2 Symbols and units

Symbol	Quantity	Unit
A	area	m^2
d	thickness	m
h	surface heat transfer coefficient	$\mathrm{W/(m^2 \cdot K)}$
R	design thermal resistance (surface to surface)	$\mathrm{m^2 \cdot K/W}$
R_g	thermal resistance of airspace	$\mathrm{m^2 \cdot K/W}$
R_se	external surface resistance	$\mathrm{m^2 \cdot K/W}$
R_si	internal surface resistance	$\mathrm{m^2 \cdot K/W}$
R_T	total thermal resistance (environment to environment)	$\mathrm{m^2 \cdot K/W}$
R'_T	upper limit of total thermal resistance	$\mathrm{m^2 \cdot K/W}$
R''_T	lower limit of total thermal resistance	$\mathrm{m^2 \cdot K/W}$
R_u	thermal resistance of unheated space	$\mathrm{m^2 \cdot K/W}$
U	thermal transmittance	$\mathrm{W/(m^2 \cdot K)}$
λ	design thermal conductivity	$\mathrm{W/(m \cdot K)}$

4 Principles

The principle of the calculation method is as follows:

- to obtain the thermal resistance of each thermally homogeneous part of the component;
- to combine these individual resistances so as to obtain the total thermal resistance of the component, including (where appropriate) the effect of surface resistances.

Thermal resistances of individual parts are obtained in accordance with 5.1.

The values of surface resistance given in 5.2 are appropriate in most cases. Annex A gives detailed procedures for low emissivity surfaces, specific external wind speeds and non-planar surfaces.

Air layers may be regarded as thermally homogeneous for the purposes of this International Standard. Values of the thermal resistance of large air layers with high emissivity surfaces are given in 5.3. Annex B provides procedures for other cases.

The resistances of the layers are combined as follows:

a) for components consisting of thermally homogeneous layers, obtain the total thermal resistance in accordance with 6.1 and the thermal transmittance in accordance with Clause 7;

b) for components having one or more thermally inhomogeneous layers, obtain the total thermal resistance in accordance with 6.2 and the thermal transmittance in accordance with Clause 7;

c) for components containing a tapered layer, obtain the thermal transmittance and/or the total thermal resistance in accordance with Annex C.

Finally, corrections are applied to the thermal transmittance, if appropriate, in accordance with Annex D, in order to allow for the effects of air voids in insulation, mechanical fasteners penetrating an insulation layer and precipitation on inverted roofs.

The thermal transmittance calculated in this way applies between the environments on either side of the component concerned, e.g. internal and external environments, two internal environments in the case of an internal partition, an internal environment and an unheated space. Simplified procedures are given in 5.4 for treating an unheated space as a thermal resistance.

NOTE Calculation of heat flow rates are commonly undertaken using operative temperature (usually approximated to the arithmetic mean of air temperature and mean radiant temperature) to represent the environment inside buildings, and air temperature to represent the external environment. Other definitions of the temperature of an environment are also used when appropriate to the purpose of the calculation. See also Annex A.

5 Thermal resistances

5.1 Thermal resistance of homogeneous layers

Design thermal values can be given as either design thermal conductivity or design thermal resistance. If thermal conductivity is given, obtain the thermal resistance of the layer from

$$R = \frac{d}{\lambda} \tag{1}$$

where

d is the thickness of the material layer in the component;

λ is the design thermal conductivity of the material, either calculated in accordance with ISO 10456 or obtained from tabulated values.

NOTE The thickness, d, can be different from the nominal thickness (e.g. when a compressible product is installed in a compressed state, d is less than the nominal thickness). If relevant, it is advisable that d also make appropriate allowance for thickness tolerances (e.g. when they are negative).

Thermal resistance values used in intermediate calculations shall be calculated to at least three decimal places.

5.2 Surface resistances

Use the values in Table 1 for plane surfaces in the absence of specific information on the boundary conditions. The values under “horizontal” apply to heat flow directions ± 30° from the horizontal plane. For non-planar surfaces or for specific boundary conditions, use the procedures in Annex A.

Table 1 — Conventional surface resistances

Surface resistance $m^2 \cdot K/W$	Direction of heat flow		
	Upwards	**Horizontal**	**Downwards**
R_{si}	0,10	0,13	0,17
R_{se}	0,04	0,04	0,04

NOTE 1 The values given are design values. For the purposes of declaration of the thermal transmittance of components and other cases where values independent of heat flow direction are required, or when the heat flow direction is liable to vary, it is advisable that the values for horizontal heat flow be used.

NOTE 2 The surface resistances apply to surfaces in contact with air. No surface resistance applies to surfaces in contact with another material.

5.3 Thermal resistance of air layers

5.3.1 Applicability

The values given in 5.3.1 to 5.3.3 apply to an air layer which

- is bounded by two faces that are effectively parallel and perpendicular to the direction of heat flow and that have emissivities not less than 0,8,
- has a thickness (in the direction of heat flow) of less than 0,1 times each one of the other two dimensions, and not greater than 0,3 m,
- has no air interchange with the internal environment.

If the above conditions do not apply, use the procedures in Annex B.

NOTE Most building materials have an emissivity greater than 0,8.

A single thermal transmittance should not be calculated for components containing air layers thicker than 0,3 m. Instead, heat flows should be calculated by performing a heat balance (see ISO 13789).

5.3.2 Unventilated air layer

An unventilated air layer is one in which there is no express provision for air flow through it. Design values of thermal resistance are given in Table 2. The values under “horizontal” apply to heat flow directions ± 30° from the horizontal plane.

An air layer having no insulation between it and the external environment, but with small openings to the external environment, shall also be considered as an unventilated air layer if these openings are not arranged so as to permit air flow through the layer and they do not exceed

- 500 mm^2 per metre of length (in the horizontal direction) for vertical air layers,
- 500 mm^2 per square metre of surface area for horizontal air layers.

NOTE Drain openings (weep holes) in the form of open vertical joints in the outer leaf of a masonry cavity wall usually conform with the above criteria and so are not regarded as ventilation openings.

Table 2 — Thermal resistance of unventilated air layers with high emissivity surfaces

Thickness of air layer	Thermal resistance m²·K/W Direction of heat flow		
mm	Upwards	Horizontal	Downwards
0	0,00	0,00	0,00
5	0,11	0,11	0,11
7	0,13	0,13	0,13
10	0,15	0,15	0,15
15	0,16	0,17	0,17
25	0,16	0,18	0,19
50	0,16	0,18	0,21
100	0,16	0,18	0,22
300	0,16	0,18	0,23

NOTE Intermediate values may be obtained by linear interpolation.

5.3.3 Slightly ventilated air layer

A slightly ventilated air layer is one in which there is provision for limited air flow through it from the external environment by openings of area, A_v, within the following ranges:

- $>$ 500 mm² but $<$ 1 500 mm² per metre of length (in the horizontal direction) for vertical air layers;
- $>$ 500 mm² but $<$ 1 500 mm² per square metre of surface area for horizontal air layers.

The effect of ventilation depends on the size and distribution of the ventilation openings. As an approximation, the total thermal resistance of a component with a slightly ventilated air layer may be calculated as

$$R_T = \frac{1500 - A_v}{1000} R_{T,u} + \frac{A_v - 500}{1000} R_{T,v} \qquad (2)$$

where

$R_{T,u}$ is the total thermal resistance with an unventilated air layer in accordance with 5.3.2;

$R_{T,v}$ is the total thermal resistance with a well-ventilated air layer in accordance with 5.3.4.

5.3.4 Well-ventilated air layer

A well-ventilated air layer is one for which the openings between the air layer and the external environment are equal to or exceed

- 1 500 mm² per metre of length (in the horizontal direction) for vertical air layers,
- 1 500 mm² per square of metre of surface area for horizontal air layers.

The total thermal resistance of a building component containing a well-ventilated air layer shall be obtained by disregarding the thermal resistance of the air layer and all other layers between the air layer and external environment, and including an external surface resistance corresponding to still air (see Annex A). Alternatively, the corresponding value of R_{si} from Table 1 may be used.

5.4 Thermal resistance of unheated spaces

5.4.1 General

When the external envelope of the unheated space is not insulated, the simplified procedures in 5.4.2 and 5.4.3, treating the unheated space as a thermal resistance, may be applied.

NOTE 1 ISO 13789 gives general and more precise procedures for the calculation of heat transfer from a building to the external environment via unheated spaces, which it is advisable to use when a more accurate result is required. For crawl spaces below suspended floors, see ISO 13370.

NOTE 2 The thermal resistances given in 5.4.2 and 5.4.3 are suitable for heat flow calculations, but not for calculations concerned with the hygrothermal conditions in the unheated space.

5.4.2 Roof spaces

For a roof structure consisting of a flat, insulated ceiling and a pitched roof, the roof space may be regarded as if it were a thermally homogeneous layer with thermal resistance as given in Table 3.

Table 3 — Thermal resistance of roof spaces

Characteristics of roof		R_u m²·K/W
1	Tiled roof with no felt, boards or similar	0,06
2	Sheeted roof, or tiled roof with felt or boards or similar under the tiles	0,2
3	As 2 (above) but with aluminium cladding or other low emissivity surface at underside of roof	0,3
4	Roof lined with boards and felt	0,3
NOTE The values in this table include the thermal resistance of the ventilated space and the thermal resistance of the (pitched) roof construction. They do not include the external surface resistance, R_{se}.		

The data in Table 3 apply to naturally ventilated roof spaces above heated buildings. If mechanically ventilated, use the detailed procedure in ISO 13789, treating the roof space as an unheated space with a specified ventilation rate.

5.4.3 Other spaces

When a building has an unheated space adjacent to it, the thermal transmittance between the internal and external environments can be obtained by treating the unheated space together with its external construction components as if it were an additional homogeneous layer with thermal resistance, R_u. When all elements between the internal environment and the unheated space have the same thermal transmittance, R_u is given by

$$R_u = \frac{A_i}{\sum_k (A_{e,k}\ U_{e,k}) + 0,33 \times nV} \tag{3}$$

where

A_i is the total area of all elements between the internal environment and the unheated space, in m²;

$A_{e,k}$ is the area of element k between the unheated space and the external environment, in m²;

$U_{e,k}$ is the thermal transmittance of element k between the unheated space and the external environment, in W/(m²·K);

n is the ventilation rate of the unheated space, in air changes per hour;

V is the volume of the unheated space, in m³;

and the summation is done over all elements between the unheated space and the external environment, except for any ground floor.

Where the details of the construction of the external elements of the unheated space are not known, the values $U_{e,k} = 2$ W/(m²·K) and $n = 3$ air changes per hour are recommended.

NOTE 1 Examples of unheated spaces include garages, store rooms and conservatories.

NOTE 2 If there is more than one component between the internal environment and the unheated space, R_u is included in the calculation of the thermal transmittance of each such component.

NOTE 3 Equation (3) is based on the procedure in ISO 13789 for the calculation of heat transfer through unheated spaces.

6 Total thermal resistance

6.1 Total thermal resistance of a building component consisting of homogeneous layers

The total thermal resistance, R_T, of a plane building component consisting of thermally homogeneous layers perpendicular to the heat flow shall be calculated by the following expression:

$$R_T = R_{si} + R_1 + R_2 + \text{........} R_n + R_{se} \tag{4}$$

where

R_{si} is the internal surface resistance;

R_1, R_2 ... R_n are the design thermal resistances of each layer;

R_{se} is the external surface resistance.

When calculating the resistance of internal building components (partitions, etc.), or a component between the internal environment and an unheated space, R_{si} applies on both sides.

If the total thermal resistance is presented as a final result, it shall be rounded to two decimal places.

NOTE The surface resistances are omitted in Equation (4) when the resistance of a component from surface to surface is required.

6.2 Total thermal resistance of a building component consisting of homogeneous and inhomogeneous layers

6.2.1 Applicability

6.2.2 to 6.2.5 provide a simplified method for calculating the thermal resistance of building components consisting of thermally homogeneous and inhomogeneous layers. The method is not valid for cases where the ratio of the upper limit of thermal resistance to the lower limit of thermal resistance exceeds 1,5. The method is not applicable to cases where insulation is bridged by metal. For metal fasteners, the method can be used as if there were no metal fasteners and the result corrected in accordance with D.3.

NOTE 1 A more precise result is obtained by using a numerical method conforming to ISO 10211. This can be particularly relevant where there is a significant difference between the thermal conductivity of materials in the layer providing the predominant thermal resistance of the construction.

NOTE 2 The method described in 6.2.2 to 6.2.5 is not suitable for computing surface temperatures for the purposes of evaluating the risk of condensation.

If part of a building element is to be assessed separately from the complete structure, its thermal resistance shall be obtained using the method in 6.2.2 to 6.2.5, but with a surface resistance equal to zero on both sides of it. This thermal resistance can then be used in a subsequent calculation to obtain the thermal transmittance of the complete element.

NOTE 3 This is relevant when part of an element is sold as a separate item. Examples could include structural panels and voided masonry units.

6.2.2 Total thermal resistance of a component

The total thermal resistance, R_T, of a component consisting of thermally homogeneous and thermally inhomogeneous layers parallel to the surface is calculated as the arithmetic mean of the upper and lower limits of the resistance:

$$R_\mathrm{T} = \frac{R'_\mathrm{T} + R''_\mathrm{T}}{2} \tag{5}$$

where

R'_T is the upper limit of the total thermal resistance, calculated in accordance with 6.2.3;

R''_T is the lower limit of the total thermal resistance, calculated in accordance with 6.2.4.

If the total thermal resistance is presented as a final result, it shall be rounded to two decimal places.

Calculation of the upper and lower limits shall be carried out by considering the component split into sections and layers, as shown in Figure 1, in such a way that the component is divided into parts, mj, which are themselves thermally homogeneous.

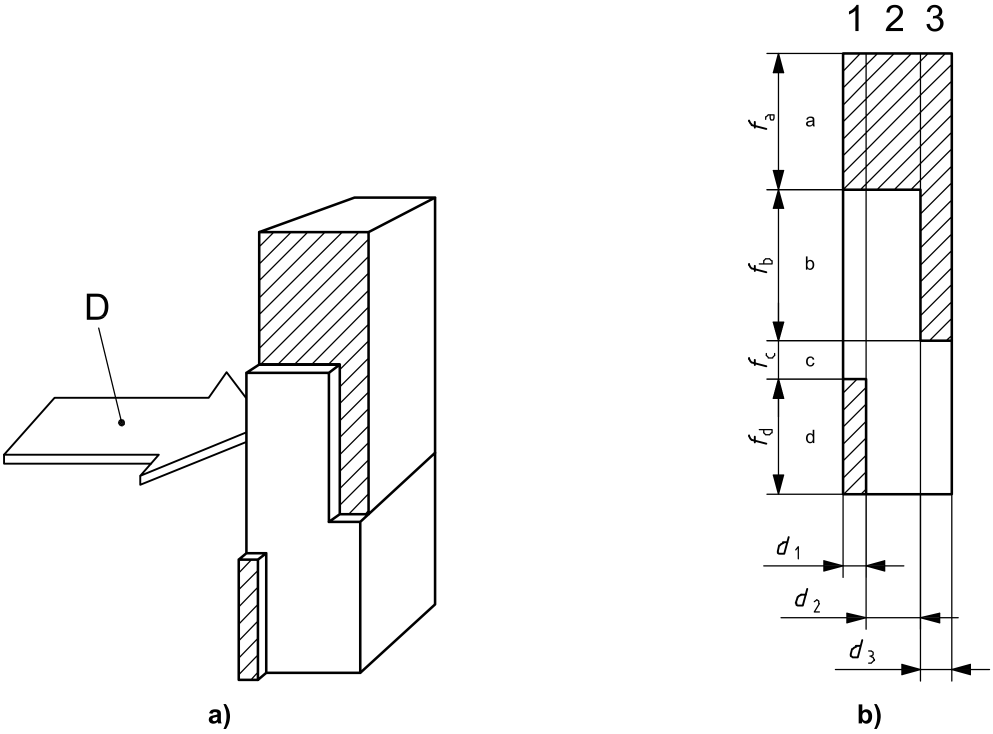
The component [see Figure 1 a)] is considered cut into sections a, b, c and d and into layers 1, 2 and 3 [see Figure 1 b)].

The section m (m = a, b, c, ... q) perpendicular to the surfaces of the component has a fractional area f_m.

The layer j (j = 1, 2, ... n) parallel to the surfaces has a thickness d_j.

The part mj has a thermal conductivity λ_{mj}, thickness d_j, fractional area f_m and thermal resistance R_{mj}.

The fractional area of a section is its proportion of the total area. Therefore, $f_a + f_b$ 1 .... $+ f_q = 1$.



Key

D heat flow direction
a, b, c, d sections
1, 2, 3 layers

Figure 1 — Sections and layers of a thermally inhomogeneous component

6.2.3 Upper limit of the total thermal resistance, R'_T

The upper limit of the total thermal resistance, R'_T, is determined by assuming one-dimensional heat flow perpendicular to the surfaces of the component. It is given by the following expression:

$$\frac{1}{R'_T} = \frac{f_a}{R_{Ta}} + \frac{f_b}{R_{Tb}} + \dots + \frac{f_q}{R_{Tq}} \qquad (6)$$

where

R_{Ta}, R_{Tb}, ..., R_{Tq} are the total thermal resistances from environment to environment for each section, calculated using Equation (4);

$f_a, f_b, \dots, f_q$ are the fractional areas of each section.

6.2.4 Lower limit of the total thermal resistance, R''_{T}

The lower limit of the total thermal resistance, R''_{T}, is determined by assuming that all planes parallel to the surfaces of the component are isothermal surfaces.1)

Calculate an equivalent thermal resistance, R_j, for each thermally inhomogeneous layer using Equation (7).2)

$$\frac{1}{R_j} = \frac{f_{\mathrm{a}}}{R_{\mathrm{a}j}} + \frac{f_{\mathrm{b}}}{R_{\mathrm{b}j}} + \ldots + \frac{f_{\mathrm{q}}}{R_{\mathrm{q}j}} \tag{7}$$

The lower limit is then determined using Equation (4), i.e.

$$R''_{\mathrm{T}} = R_{\mathrm{si}} + R_1 + R_2 + \ldots + R_n + R_{\mathrm{se}} \tag{8}$$

6.2.5 Estimation of error

This method of estimating the maximum relative error may be used when the calculated thermal transmittance is required to meet specified accuracy criteria.

The maximum relative error, e, when using this approximation, calculated as a percentage, is:

$$e = \frac{R'_{\mathrm{T}} - R''_{\mathrm{T}}}{2R_{\mathrm{T}}} \times 100 \tag{9}$$

EXAMPLE If the ratio of the upper limit to the lower limit is 1,5, the maximum possible error is 20 %.

The actual error is usually much less than the maximum. This error may be evaluated to decide whether the accuracy obtained through the procedure described in 6.2.2 is acceptable with regard to

- the purpose of the calculation,
- the proportion of the total heat flow through the building fabric that is transmitted through the components, the thermal resistance of which is evaluated through the procedure described in 6.2.2,
- the accuracy of the input data.

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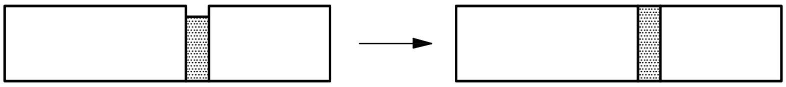
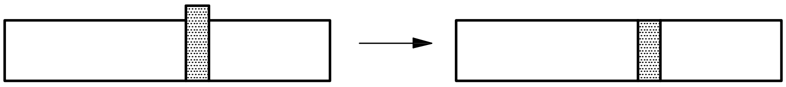
1) If there is a non-planar surface adjacent to an air layer, the calculation should be undertaken as if it were planar by considering the narrower sections extended (but without alteration to thermal resistance):



or the projecting parts removed (so reducing the thermal resistance):



2) An alternative method giving the same result is by means of an equivalent thermal conductivity of the layer:

$$R_j = d_j / \lambda''_j$$

where the equivalent thermal conductivity λ''_j of layer j is

$$\lambda''_j = \lambda_{\mathrm{a}j} f_{\mathrm{a}} + \lambda_{\mathrm{b}j} f_{\mathrm{b}} + \ldots + \lambda_{\mathrm{q}j} f_{\mathrm{q}}$$

If an air layer is part of an inhomogeneous layer, it may be treated as a material with an equivalent thermal conductivity $\lambda''_j = d_j / R_{\mathrm{g}}$, where R_{g} is the thermal resistance of the air layer determined in accordance with Annex B.

7 Thermal transmittance

The thermal transmittance is given by

$$U = \frac{1}{R_{\mathrm{T}}} \tag{10}$$

Corrections shall be applied to the thermal transmittance, as appropriate, in accordance with Annex D. If, however, the total correction is less than 3 % of U, the corrections need not be applied.

If the thermal transmittance is presented as a final result, it shall be rounded to two significant figures, and information shall be provided on the input data used for the calculation.

Annex A
(normative)

Surface resistance

A.1 Plane surfaces

The surface resistance is given by Equation (A.1).[3]

$$R_s = \frac{1}{h_c + h_r} \quad (A.1)$$

where

h_c is the convective coefficient;

h_r is the radiative coefficient;

and

$$h_r = \varepsilon h_{r0} \quad (A.2)$$

$$h_{r0} = 4\sigma T_m^3 \quad (A.3)$$

where

ε is the hemispherical emissivity of the surface;

h_{r0} is the radiative coefficient for a black-body surface (see Table A.1), in W/(m²·K);

σ is the Stefan-Boltzmann constant [5,67 × 10^{-8} W/(m²K⁴)];

T_m is the mean thermodynamic temperature of the surface and of its surroundings, in K.

$\varepsilon = 0{,}9$ is usually appropriate for internal and external surfaces. Where other values are used, they should allow for any effects of deterioration and dust accumulation with time.

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[3] This is an approximate treatment of surface heat transfer. Precise calculations of heat flow can be based on the internal and external environmental temperatures (in which the radiant and air temperatures are weighted according to the respective radiative and convective coefficients, and which can also take account of room geometry effects, air temperature gradients and forced convection). If, however, the internal radiant and air temperatures are not markedly different, the operative temperature (taken as equal weighting of air and radiant temperatures) may be used. At external surfaces it is conventional to use the external air temperature, based on an assumption of overcast sky conditions, so that external air and radiant temperatures are effectively equal. This ignores any effect of short-wave solar radiation on external surfaces, dew formation, radiation to the night sky and the effect of nearby surfaces. Other indexes of external temperature, such as radiation-air temperature or sol-air temperature, may be used when such effects are to be allowed for.

Table A.1 — Values of the black-body radiative coefficient, h_{r0}

Mean temperature °C	h_{r0} W/(m²·K)
−10	4,1
0	4,6
10	5,1
20	5,7
30	6,3

At internal surfaces, or external surfaces adjacent to a well-ventilated air layer (see 5.3.4),

$$h_c = h_{ci} \tag{A.4}$$

where

$h_{ci} = 5{,}0$ W/(m²·K) for heat flow upwards;

$h_{ci} = 2{,}5$ W/(m²·K) for heat flow horizontal;

$h_{ci} = 0{,}7$ W/(m²·K) for heat flow downwards.

At external surfaces,

$$h_c = h_{ce} \tag{A.5}$$

where

$$h_{ce} = 4 + 4v \tag{A.6}$$

and v is the wind speed adjacent to the surface, in m/s.

Values of the external surface resistance, R_{se}, for various wind speeds are given in Table A.2.

NOTE The values given in 5.2 for internal surface resistance are calculated for $\varepsilon = 0{,}9$ and with h_{r0} evaluated at 20 °C. The value given in 5.2 for external surface resistance is calculated for $\varepsilon = 0{,}9$, h_{r0} evaluated at 10 °C, and for $v = 4$ m/s.

Table A.2 — Values of R_{se} at various wind speeds

Wind speed m/s	R_{se} m²·K/W
1	0,08
2	0,06
3	0,05
4	0,04
5	0,04
7	0,03
10	0,02

A.2 Components with non-planar surfaces

Parts which protrude from otherwise plane surfaces, such as structural columns, shall be disregarded in the calculation of the total thermal resistance if composed of material having a thermal conductivity not greater than 2,5 W/(m·K). If the part that protrudes is composed of material having a thermal conductivity greater than 2,5 W/(m·K), and if it is not insulated, the calculation shall be done as if the protruding part were not present but with the surface resistance over the applicable area multiplied by the ratio of the projected area to the actual surface area of the protruding part (see Figure A.1):

$$R_{\mathrm{sp}} = R_{\mathrm{s}} \frac{A_{\mathrm{p}}}{A} \tag{A.7}$$

where

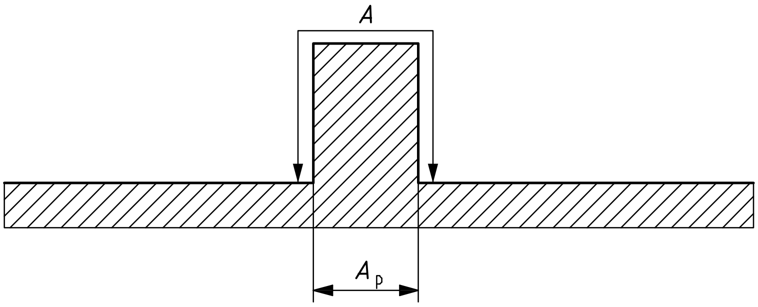
R_{sp} is the surface resistance over the projected area of the protruding part;

R_{s} is the surface resistance of a plane component in accordance with A.1;

A_{p} is the projected area of the protruding part;

A is the actual surface area of the protruding part.

Equation (A.7) applies to both internal and external surface resistance.



Key

A actual surface area of the protruding part

A_{p} projected area of the protruding part

Figure A.1 — Actual and projected areas

Annex B
(normative)

Thermal resistance of airspaces

B.1 General

This annex applies to airspaces in building components other than glazing. A more precise treatment is necessary for glazing and window frames.

The term airspace includes both air layers (which have a width and length both 10 times the thickness, with thickness measured in the heat flow direction) and air voids (which have a width or length comparable to the thickness). If the thickness of the air layer varies, its average value should be used to calculate the thermal resistance.

NOTE Airspaces can be treated as media with thermal resistance because the radiation and convection heat transfer across them is approximately proportional to the temperature difference between the bounding surfaces.

B.2 Unventilated airspaces with length and width both more than 10 times thickness

The thermal resistance of an airspace is given by

$$R_\mathrm{g} = \frac{1}{h_\mathrm{a} + h_\mathrm{r}} \tag{B.1}$$

where

R_g is the thermal resistance of the airspace;

h_a is the conduction/convection coefficient;

h_r is the radiative coefficient.

h_a is determined by conduction in still air for narrow airspaces and by convection in wide cavities. For calculations in accordance with this International Standard, it is the larger of $0{,}025/d$ and the value of h_a obtained from Table B.1 or Table B.2. In Tables B.1 and B.2, d is the thickness of the airspace in the direction of heat flow, in metres, and ΔT is the temperature difference across the airspace, in kelvins.

Table B.1 should be used when the temperature difference across the airspace is less than or equal to 5 K.

Table B.1 — Convective heat transfer coefficient for temperature difference $\Delta T \leqslant 5$ K

Direction of heat flow	h_a [a] W/(m²·K)
Horizontal	1,25
Upwards	1,95
Downwards	$0{,}12 \times d^{-0{,}44}$

[a] Or, if larger, $0{,}025/d$.

Table B.2 should be used when the temperature difference across the airspace exceeds 5 K.

Table B.2 — Convective heat transfer coefficient for temperature difference $\Delta T > 5$ K

Direction of heat flow	h_a [a] W/(m²·K)
Horizontal	$0{,}73 \times (\Delta T)^{1/3}$
Upwards	$1{,}14 \times (\Delta T)^{1/3}$
Downwards	$0{,}09 \times (\Delta T)^{0{,}187} d^{-0{,}44}$

[a] Or, if larger, 0,025/*d*.

h_r is given by

$$h_r = E\, h_{r0} \tag{B.2}$$

where

E is the intersurface emittance;

h_{r0} is the radiative coefficient for a black-body surface (see Table A.1);

and

$$E = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \tag{B.3}$$

where ε_1, ε_2 are the hemispherical emissivities of the surfaces bounding the airspace.

The design value of emissivity should allow for any effects of deterioration and dust accumulation with time.

NOTE The values in Table B.2 are calculated using Equation (B.1) with $\varepsilon_1 = 0{,}9$, $\varepsilon_2 = 0{,}9$, and h_{r0} evaluated to 10 °C.

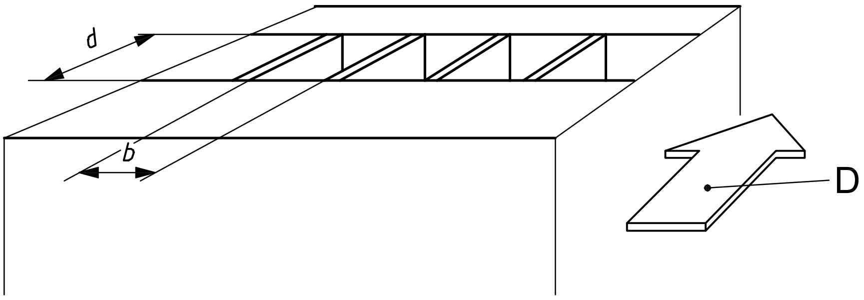
B.3 Ventilated airspaces with length and width both more than 10 times thickness

For a slightly ventilated airspace (as defined in 5.3.3), follow the procedure specified in 5.3.3.

For a well-ventilated airspace (as defined in 5.3.4), follow the procedure specified in 5.3.4.

B.4 Small or divided unventilated airspaces (air voids)

Figure B.1 illustrates a small airspace with a width less than 10 times its thickness.



Key

b	width of the airspace
d	thickness of the airspace
D	heat flow direction

Figure B.1 — Dimensions of small airspace

The thermal resistance of the airspace, R_g, is given by

$$R_g = \frac{1}{h_a + h_r} \tag{B.4}$$

where

$$h_r = \frac{h_{r0}}{\dfrac{1}{\varepsilon_1} + \dfrac{1}{\varepsilon_2} - 2 + \dfrac{2}{\left(1 + \sqrt{1 + d^2/b^2} - d/b\right)}} \tag{B.5}$$

where

d is the thickness of the airspace;

b is the width of the airspace;

ε_1, ε_2 are the hemispherical emissivities of the surfaces on the warm and cold faces of the airspace.

h_a and h_{r0} are calculated as in B.2.

NOTE 1 h_a depends on d, but is independent of b.

NOTE 2 Equation (B.4) is appropriate for the calculation of heat flow through building components for any thickness of air void, and for the calculation of temperature distributions in building components having air voids whose thickness, d, is less than or equal to 50 mm. For thicker air voids, the equation gives an approximate temperature distribution.

For an air void that is not rectangular in shape, take its thermal resistance as equal to that of a rectangular void which has the same area and aspect ratio as the actual void.

Annex C
(normative)

Calculation of the thermal transmittance of components with tapered layers

C.1 General

When a component has a tapered layer (e.g. in external roof insulation layers to establish fall), the total thermal resistance varies over the area of the component.

NOTE 1 For tapered air layers, see B.1.

Components with a tapered layer are built up as shown in Figure C.1.

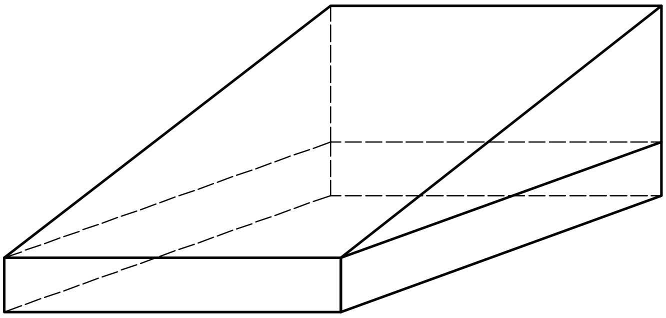


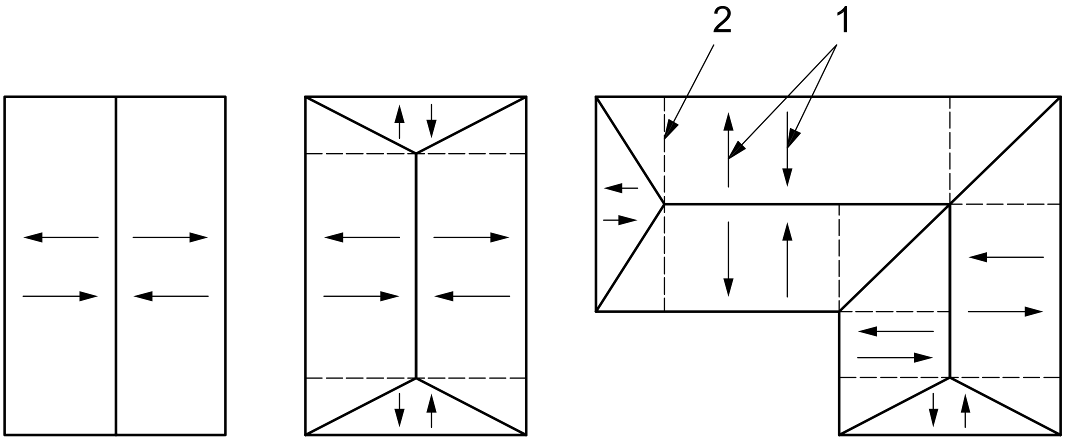
Figure C.1 — Principle of build-up of component

The thermal transmittance is defined by an integral over the area of the relevant component.

The calculation shall be carried out separately for each part (e.g. of a roof) with different pitch and/or shape, as shown in Figure C.2.

In addition to the symbols listed in Clause 3, the following symbols are used in this annex:

Symbol	Quantity	Unit
d_1	intermediate thickness of the tapered layer	m
d_2	maximum thickness of the tapered layer	m
ln	natural logarithm	—
R_0	design thermal resistance of the remaining part, including surface resistances on both sides of the component	$m^2 \cdot K/W$
R_1	intermediate thermal resistance of the tapered layer	$m^2 \cdot K/W$
R_2	maximum thermal resistance of the tapered layer	$m^2 \cdot K/W$
λ_t	design thermal conductivity of the tapered part (having zero thickness at one end)	W/(m·K)



Key

1 direction of pitch (can be in either direction)

2 alternative (supplementary) subdivision to enable use of Equations (C.1) to (C.4)

Figure C.2 — Examples of how to subdivide roofs into individual parts

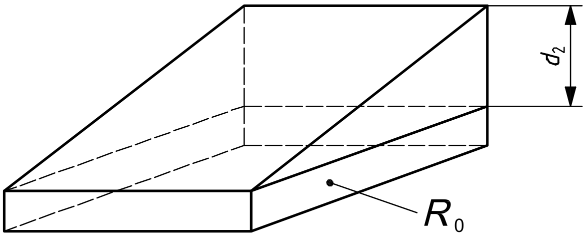
The thermal transmittance of common shapes shall be calculated by Equations (C.1) to (C.4) for pitches not exceeding 5 %.

NOTE 2 Numerical methods can be used for greater pitches.

C.2 Calculation for common shapes

C.2.1 Rectangular area

$$U = \frac{1}{R_2} \ln \left(1 + \frac{R_2}{R_0} \right) \qquad \text{(C.1)}$$



Key

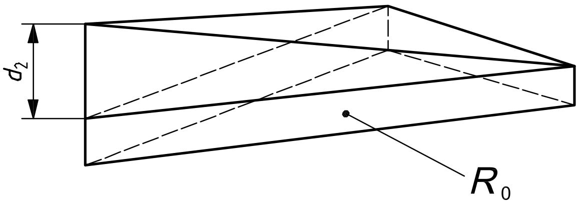
d_2 maximum thickness of the tapered layer

R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure C.3 — Rectangular area

C.2.2 Triangular area, thickest at apex

$$U = \frac{2}{R_2}\left[\left(1+\frac{R_0}{R_2}\right)\ln\left(1+\frac{R_2}{R_0}\right)-1\right] \tag{C.2}$$



Key

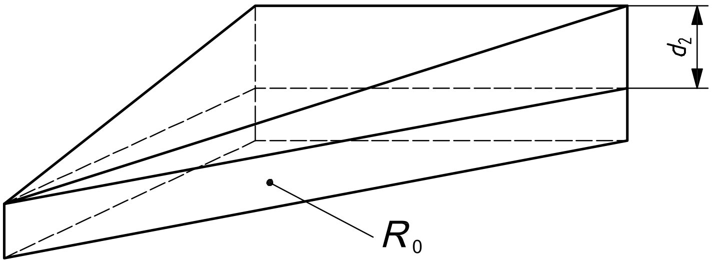
d_2 maximum thickness of the tapered layer

R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure C.4 — Triangular area, thickest at apex

C.2.3 Triangular area, thinnest at apex

$$U = \frac{2}{R_2}\left[1 - \frac{R_0}{R_2}\ln\left(1+\frac{R_2}{R_0}\right)\right] \tag{C.3}$$



Key

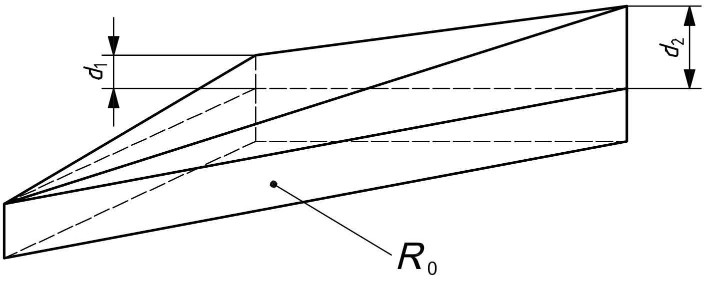
d_2 maximum thickness of the tapered layer

R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure C.5 — Triangular area, thinnest at apex

C.2.4 Triangular area, different thickness at each vertex

$$U = 2\left[\frac{R_0 R_1 \ln\left(1+\frac{R_2}{R_0}\right) - R_0 R_2 \ln\left(1+\frac{R_1}{R_0}\right) + R_1 R_2 \ln\left(\frac{R_0+R_2}{R_0+R_1}\right)}{R_1 R_2 \left(R_2 - R_1\right)}\right] \qquad \text{(C.4)}$$



$0 < d_1 < d_2$

Key

d_1 intermediate thickness of the tapered layer

d_2 maximum thickness of the tapered layer

R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure C.6 — Triangular area, different thickness at each vertex

C.3 Calculation procedure

The calculation shall be carried out as described below.

a) Calculate R_0 as the total thermal resistance of the component excluding the tapered layer, using Equation (4) if all layers are thermally homogeneous, or the procedure in 6.2 if there are inhomogeneous layers.

b) Subdivide the area with tapered layers into individual parts, as necessary (see Figure C.2).

c) Calculate R_1 and R_2 for each tapered layer, using

$$R_1 = \frac{d_1}{\lambda_t} \qquad \text{(C.5)}$$

$$R_2 = \frac{d_2}{\lambda_t} \qquad \text{(C.6)}$$

NOTE R_1 is used only for the shape illustrated in Figure C.6.

d) Calculate the thermal transmittance of each individual part, U_i, in accordance with the relevant equation in C.2.

e) Calculate the overall thermal transmittance for the whole area using

$$U = \frac{\sum U_i A_i}{\sum A_i} \qquad \text{(C.7)}$$

If total thermal resistance of a component with tapered layers is required, then

$$R_T = 1/U \qquad \text{(C.8)}$$

Annex D
(normative)

Corrections to thermal transmittance

D.1 General

The thermal transmittance obtained by the procedures given in this International Standard shall be corrected where relevant to allow for the effects of

— air voids in insulation,

— mechanical fasteners penetrating an insulation layer,

— precipitation on inverted roofs.

NOTE An inverted roof is one which has an insulation layer above the waterproof membrane.

The corrected thermal transmittance, U_c, is obtained by adding a correction term, ΔU:

$$U_\mathrm{c} = U + \Delta U \tag{D.1}$$

ΔU is given by

$$\Delta U = \Delta U_\mathrm{g} + \Delta U_\mathrm{f} + \Delta U_\mathrm{r} \tag{D.2}$$

where

ΔU_g is the correction for air voids in accordance with (D.2);

ΔU_f is the correction for mechanical fasteners in accordance with (D.3);

ΔU_r is the correction for inverted roofs in accordance with (D.4).

D.2 Correction for air voids

D.2.1 Definitions

For the purposes of this annex, “air voids” is used as the general term for airspaces in the insulation, or between the insulation and the adjacent construction, which exist in actual building constructions but are not shown on drawings. They can be divided in two main categories:

— gaps, between insulating boards, slabs or mats or between the insulation and construction elements, in the direction of the heat flow;

— cavities, in the insulation or between the insulation and the construction, perpendicular to the direction of the heat flow.

D.2.2 Corrections

Air voids may increase the thermal transmittance of the component by increasing the heat transfer by radiation and convection: the magnitude of the increase depends on the size, orientation and position of the air void.

The correction is applied as an addition to the thermal transmittance expressed as ΔU_g.

Air gaps are caused by small variations in the dimensions of the insulation product (dimensional tolerances), by variations from the required sizes during cutting and installation, and because of the dimensional tolerances associated with the construction itself and its irregularities.

Only gaps bridging the entire insulation thickness from hot to cold side cause an increase of the transmittance such that a correction is justified, which in general is only a moderate correction. Installing the insulation in more than one layer with staggered joints removes the necessity for correction.

Cavities are due to non-planar surfaces within the construction: the insulation is too stiff, too inflexible or too incompressible to follow these completely. Irregularities such as mortar snots, which act as spacers creating an airspace or airspaces between the construction and the insulation, produce the same effect. When the cavities are discontinuous (no communication with other air cavities, air gaps or the internal or external environments), only a moderate correction is applied.

For both types of air void, comparison of calculation and measurement show good agreement.

If the two types of air void are combined, additional heat losses may result due to mass transfer, requiring a larger correction to be applied.

Workmanship is always assumed to be of an adequate standard.

In order to simplify the correction procedure, the way of installing the insulation is used as a basis for the correction. Three levels are identified (see Table D.1).

Table D.1 — Corrections for air voids, $\Delta U''$

Level	Description	$\Delta U''$ W/(m^2·K)
0	No air voids within the insulation, or where only minor air voids are present that have no significant effect on the thermal transmittance.	0,00
1	Air gaps bridging between the hot and cold side of the insulation, but not causing air circulation between the warm and cold side of the insulation.	0,01
2	Air gaps bridging between the hot and cold side of the insulation, combined with cavities resulting in free air circulation between the warm and cold sides of the insulation.	0,04

This correction is adjusted in accordance with Equation (D.3):

$$\Delta U_\mathrm{g} = \Delta U'' \left(\frac{R_1}{R_\mathrm{T,h}} \right)^2 \tag{D.3}$$

where

R_1 is the thermal resistance of the layer containing gaps, as obtained in 5.1;

$R_\mathrm{T,h}$ is the total thermal resistance of the component ignoring any thermal bridging, as obtained in 6.1;

$\Delta U''$ is given by Table D.1.

D.2.3 Examples

The following are indicative examples of the correction levels. Specific examples related to local construction techniques can be provided on a national basis.

a) Examples of level 0 (correction $\Delta U'' = 0$ is applied)

- Continuous layers of insulation, without any interruptions of the insulation layer by construction elements, e.g. studs, rafters or joists, with staggered joints between the mats or boards in the individual layers. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.
- More than one layer, where one layer is continuous, without any interruptions of the insulation layer by construction elements, e.g. studs, rafters or joists, covering other layer(s) penetrated by construction elements. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.
- Single layer of continuous insulation with joints such as shiplap, tongue and groove, or sealed. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.
- Single layer of continuous insulation with butt joints, where dimensional tolerances on length, width and squareness combined with dimensional stability results in gaps at joints that are less than 5 mm wide. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.
- Single layer of insulation in a construction, where the thermal resistance of the insulation is less than or equal to half the total thermal resistance of the construction. The insulation is in firm contact with construction, without cavities between the construction and the insulation.

b) Examples of level 1 (correction $\Delta U'' = 0{,}01$ is applied)

- One layer of insulation, interrupted by construction elements, e.g. studs, rafters or joists. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.
- Single layer of continuous insulation with butt joints, where dimensional tolerances on length, width and squareness combined with dimensional stability result in gaps in joints more than 5 mm wide. The insulation is in firm contact with the construction, without cavities between the construction and the insulation.

c) Examples of level 2 (correction $\Delta U'' = 0{,}04$ is applied)

- One or more layers of insulation with no firm contact with the warm side of the construction, with cavities between the construction and the insulation resulting in air movement between the warm and cold side of the insulation.

D.3 Correction for mechanical fasteners

D.3.1 Detailed calculation

The effect of mechanical fasteners can be assessed by calculations in accordance with ISO 10211 in order to obtain the point thermal transmittance, χ, due to one fastener. The correction to the thermal transmittance is then given by

$$\Delta U_{\mathrm{f}} = n_{\mathrm{f}}\, \chi \qquad \text{(D.4)}$$

where n_{f} is the number of fasteners per square metre.

D.3.2 Approximate procedure

This subclause provides an approximate procedure for assessing the effect of mechanical fasteners, which can be used if fasteners are not accounted for by other methods.

When an insulation layer is penetrated by mechanical fasteners, such as wall ties between masonry leaves, roof fasteners or fasteners in composite panel systems, the correction to the thermal transmittance is given by

$$\Delta U_{\mathrm{f}} = \alpha \frac{\lambda_{\mathrm{f}} A_{\mathrm{f}} n_{\mathrm{f}}}{d_0} \left(\frac{R_1}{R_{\mathrm{T,h}}} \right)^2 \qquad \text{(D.5)}$$

where the coefficient α is given by

$\alpha = 0{,}8$ if the fastener fully penetrates the insulation layer,

$\alpha = 0{,}8 \times \frac{d_1}{d_0}$ in the case of a recessed fastener (see Figure D.1)

In these expressions,

λ_{f} is the thermal conductivity of the fastener, in W/(m·K);

n_{f} is the number of fasteners per square metre;

A_{f} is the cross-sectional area of one fastener, in m^2;

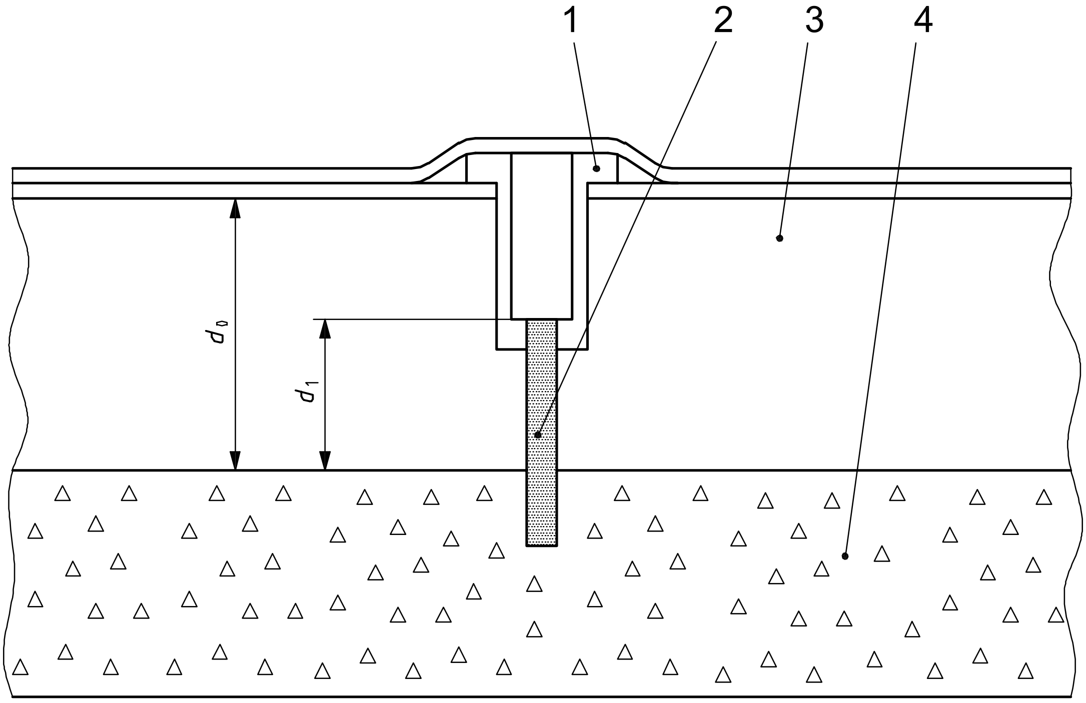
d_0 is the thickness of the insulation layer containing the fastener, in m;

d_1 is the length of the fastener that penetrates the insulation layer, in m;

R_1 is the thermal resistance of the insulation layer penetrated by the fasteners, in m^2·K/W;

$R_{\mathrm{T,h}}$ is the total thermal resistance of the component ignoring any thermal bridging, as obtained in 6.1, in m^2·K/W.

NOTE 1 d_1 can be greater than the thickness of the insulation layer if the fastener passes through it at an angle. In the case of a recessed fastener, d_1 is less than the thickness of the insulation layer and R_1 is equal to d_1 divided by the thermal conductivity of the insulation.



Key

1 plastic cup

2 recessed fastener

3 insulation

4 roof deck

d_0 thickness of the insulation layer containing the fastener

d_1 length of the fastener that penetrates the insulation layer

Figure D.1 — Recessed roof fastener

No correction shall be applied in the following cases:

- where there are wall ties across an empty cavity;
- when the thermal conductivity of the fastener is less than 1 W/(m·K).

The procedure does not apply when both ends of the metallic part of the fastener are in direct thermal contact with metal sheets.

NOTE 2 The methods in ISO 10211 can be used to obtain correction factors for cases when both ends of the fastener are in direct thermal contact with metal sheets.

D.4 Correction procedure for inverted roofs

D.4.1 General

A correction procedure is given for inverted roofs due to rainwater flowing between the insulation and the waterproofing membrane. It applies to heated buildings: for cooled buildings, the correction is not applied.

The procedure described in this clause is applicable only to insulation made from extruded polystyrene (XPS).

D.4.2 Correction due to water flowing between the insulation and the waterproofing membrane

The correction to the calculated thermal transmittance of the roof element, ΔU_r, calculated in W/(m^2·K), taking into account the extra heat loss caused by rainwater flowing through joints in the insulation and reaching the waterproofing membrane, is calculated as follows:

$$\Delta U_\mathrm{r} = p\,f\,x \left(\frac{R_1}{R_\mathrm{T}} \right)^2 \qquad \text{(D.6)}$$

where

p is the average rate of precipitation during the heating season, based upon data relevant for the location (e.g. weather station) or given through local, regional or national regulations, or other national documents or standards, in mm/day;

f is the rainage factor giving the fraction of p reaching the waterproofing membrane;

x is the factor for increased heat loss caused by rainwater flowing on the membrane, in (W·day)/(m^2·K·mm)

R_1 is the thermal resistance of the layer of insulation above the waterproofing membrane, in m^2·K/W;

R_T is the total thermal resistance of the construction before application of the correction, in m^2·K/W.

Values of p may be specified on a national basis.

For a single layer of insulation above the membrane, with butt joints and open covering such as gravel, $(f\,x) = 0{,}04$.

NOTE The single layer of insulation with butt joints and open covering is considered to be the layout giving the highest ΔU.

Lower values of $(f\,x)$ can apply for roof constructions that give less drainage through the insulation. Examples are different jointing arrangements (such as shiplap or tongue-and-groove joints), or different types of roof build-up. In these cases, where the effect of the measures are documented in independent reports, values smaller than 0,04 for $(f\,x)$ may be used.

Bibliography

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

[2] ISO 13370, *Thermal performance of buildings — Heat transfer via the ground — Calculation methods*

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