DRAFT INTERNATIONAL STANDARD
ISO/DIS 6946

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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

ICS: 91.060.01;91.120.10

ISO/CEN PARALLEL PROCESSING

This draft has been developed within the International Organization for Standardization (ISO), and processed under the **ISO lead** mode of collaboration as defined in the Vienna Agreement.

This draft is hereby submitted to the ISO member bodies and to the CEN member bodies for a parallel five month enquiry.

Should this draft be accepted, a final draft, established on the basis of comments received, will be submitted to a parallel two-month approval vote in ISO and formal vote in CEN.

To expedite distribution, this document is circulated as received from the committee secretariat. ISO Central Secretariat work of editing and text composition will be undertaken at publication stage.

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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.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT) see the following URL: Foreword - Supplementary information

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 third edition cancels and replaces the second edition (ISO 6946:2007), which has been technically revised.

The changes in the third edition are mostly editorial. The standard has been re-drafted according to CEN/TS 16629:2014, *Thermal Performance of Buildings — Detailed Technical Rules for the set of EPB standards*.

Introduction

This International Standard is part of a series of standards aiming at international harmonization of the methodology for the assessment of the energy performance of buildings, called “EPB set of standards”.

As part of the “EPB set of standards” it complies with the requirements for the set of basic EPB documents (EN 15603 (see Normative references), CEN/TS 16628 and CEN/TS 16629 (see bibliography[1] and[2]) developed under a mandate given to CEN by the European Commission and the European Free Trade Association (Mandate M/480), and supports essential requirements of EU Directive 2010/31/EC on the energy performance of buildings (EPBD).

Where appropriate, the method(s) in each of the EPB standards may provide simplified procedures and/or default values as alternative options.

— Without further specification, these simplified procedures and/or default values may be used without restricting criteria.

NOTE 1 For instance because these are conservative procedures or values.

NOTE 2 The term ‘default values’ should not be confused with ‘informative values’. If the values are given in the normative part of the standard, they are normative values.

— In other cases, these simplified procedures and/or default values may be intended to be used only for situations where there is limited information. This may be the case in existing buildings with limited possibilities to acquire all input data. In particular when the EPB set of standards is used in the context of national or regional building regulations, specific criteria when the simplified method and/or default data are allowed, may be given at national or regional level, following the template in Annex A. Annex B provides (informative) default choices.

The set of EPB standards prepared under the responsibility of ISO/TC 163/SC 2 (Thermal performance and energy use in the built environment, Calculation methods) range from calculation procedures on the overall energy use and energy performance of buildings, calculation procedures on the indoor temperature in buildings (e.g. in case of no space heating or cooling) and calculation methods covering the performance and thermal, hygrothermal, solar and visual characteristics of specific parts of the building and specific building elements and components, such as opaque envelope elements, ground floor, windows and facades. ISO/TC 163/SC 2 cooperates with other TC’s for the details on e.g. appliances, technical building systems and indoor environment.

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.

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 up to 0,3 m thickness).

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 F. Other cases where insulation is bridged by metal are outside the scope of this International Standard.

Table 1 shows the relative position of this International Standard within the EPB set of standards.

Table 1 — Position of this International Standard within the modular EPB set of standards[a]

	Overarching	Building (as such)	Technical Building Systems										
Submodule	**Descriptions**	**Descriptions**	**Descriptions**	**Heating**	**Cooling**	**Ventilation**	**Humidification**	**Dehumidification**	**Domestic Hot water**	**Lighting**	**Building automation and control**	**PV, wind, ..**
sub1	**M1**	**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
1	General	General	General									
2	Common terms and definitions; symbols, units and subscripts	Building Energy Needs	Needs									
3	Applications	(Free) Indoor Conditions without Systems	Maximum Load and Power									
4	Ways to Express Energy Performance	Ways to Express Energy Performance	Ways to Express Energy Performance									
5	Building Functions and Building Boundaries	Heat Transfer by Transmission[a]	Emission and control									

[a] Position of this International Standard: M2-5

Table 1 *(continued)*

	Overarching	Building (as such)	Technical Building Systems										
Submodule	**Descriptions**	**Descriptions**	**Descriptions**	**Heating**	**Cooling**	**Ventilation**	**Humidification**	**Dehumidification**	**Domestic Hot water**	**Lighting**	**Building automation and control**	**PV, wind, ..**
sub1	**M1**	**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
6	Building Occupancy and Operating Conditions	Heat Transfer by Infiltration and Ventilation	Distribution and control									
7	Aggregation of Energy Services and Energy Carriers	Internal Heat Gains	Storage and control									
8	Building Partitioning	Solar Heat Gains	Generation and control									
9	Calculated Energy Performance	Building Dynamics (thermal mass)	Load dispatching and operating conditions									
10	Measured Energy Performance	Measured Energy Performance	Measured Energy Performance									
11	Inspection	Inspection	Inspection									
12	Ways to Express Indoor Comfort		BMS									
13	External Environment Conditions											
14	Economic Calculation											

[a] Position of this International Standard: M2-5

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

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*

EN 15603[1)], *Energy performance of buildings – Overall energy use and definition of energy ratings*

3 Terms and definitions

For the purposes of this International Standard, the terms and definitions given in ISO 7345, EN 15603, and the following specific definitions apply.

3.1
building element
major part of a building such as a wall, floor or roof

3.2
building component
building element or a part of it

Note 1 to entry: In this International Standard, the word “component” is used to indicate both element and component.

3.3
design thermal value
design thermal conductivity or design thermal resistance

Note 1 to entry: The design value includes possible degrading effects from e.g. ageing, moisture and/or convection. In contrast to the declared value, the expected value of a thermal property of a building material or product assessed from measured data at reference conditions of temperature and humidity, see ISO 10456.

3.4
design thermal conductivity
value of thermal conductivity of a building material or product under specific external and internal conditions which can be considered as typical of the performance of that material or product when incorporated in a building component

3.5
design thermal resistance
value of thermal resistance of a building product under specific external and internal conditions which can be considered as typical of the performance of that product when incorporated in a building component

3.6
thermally homogeneous layer
layer of constant thickness having thermal properties which may be regarded as being uniform

4 Symbols and subscripts

4.1 Symbols

For the purposes of this International Standard, the symbols given in EN 15603 and the specific symbols listed in Table 2 apply.

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1) EN 15603:2008 is under revision, new edition to be published.

Table 2 — Symbols and units

Symbol	Quantity	Unit
A	area	m^2
d	thickness	m
h	heat transfer coefficient	$W/(m^2·K)$
R	thermal resistance	$m^2·K/W$
U	thermal transmittance	$W/(m^2·K)$
V	volume	m^2
λ	design thermal conductivity	W/(m·K)

4.2 Subscripts

For the purposes of this International Standard, the subscripts given in EN 15603 and the specific subscripts listed in Table 3 apply.

Table 3 — Subscripts

Subscript	Identification
a	air
c	component
eq	equivalent
e	external
nve	not ventilated
op	opaque
s	surface
si	internal surface
se	external surface
tot	total
tot;upper	upper limit of total value
tot;lower	lower limit of total value
u	unheated
ve	ventilated

5 Description of the method

5.1 Output

The output of this International Standard is the thermal resistance and thermal transmittance of a building component or building element. These quantities are calculated as a function of the thermal properties, composition and geometry of the element and the boundary conditions.

5.2 General description

There are two methods for calculating the thermal transmittance of a building component, as set out in 5.3 and 5.4.

In both cases the thermal resistance is calculated from the thermal transmittance and the applicable surface resistances according to 6.6.

5.3 Detailed calculation method

The detailed calculation method is a numerical simulation carried out in accordance with ISO 10211. This method is valid for any building component.

5.4 Simplified calculation method

The simplified calculation method is described in Clause 6 of this International Standard. It is valid for components consisting of thermally homogenous or inhomogeneous layers and which may contain air layers up to 0,3 m thick and metal fasteners, and is subject to the limitations in 6.7.2.1.

6 Calculation of thermal transmittance and thermal resistance

6.1 Output data

The output data are listed in Table 4.

Table 4 — Output data

Description	Symbol	Unit	Destination module (Table 1)	Validity interval	Varying
thermal transmittance of elements or components with horizontal heat flow	U	W/(m²·K)	M 2-5	0...∞	No
thermal transmittance of elements or components with upwards heat flow	U	W/(m²·K)	M2-5	0...∞	No
thermal transmittance of elements or components with downwards heat flow	U	W/(m²·K)	M2-5	0...∞	No
thermal resistance of opaque component	Rc;op	W/(m²·K)	M2-5	0...∞	No

6.2 Calculation time steps

The input, the method and the output data are for steady-state conditions and assumed to be independent of actual conditions, such as indoor temperature or effect of wind or solar radiation.

6.3 Input data

Tables 5, 6 and 7 list identifiers for input data required for the calculation.

Table 5 — Identifiers for geometric characteristics

Name	Symbol	Software name	Unit	Value	Range	Origin	Varying
area	A	*A*	m²		0...∞		No
thickness of material layer	d	*d*	m		0...∞		No

Table 6 — Identifiers for thermal characteristics of a building component

Name	Symbol	Software name	Unit	Value	Range	Origin	Varying
design thermal conductivity	λ	*lambda*	W/(m·K)		0...10	ISO 10456	No

Table 7 — Identifiers for tabulated and conventional values

Name	Symbol	Software name	Unit	Value	Range	Origin	Varying
external surface resistance	R_{se}		m²·K/W	0,04	N/A	Annex C	No
internal surface resistance	R_{si}		m²·K/W	-	0.1...0,17	Annex C	No
thermal resistance of unheated spaces	R_{u}		m²·K/W		0,06...0.3	Table 10	No
thermal resistance of air layer	R_{a}		m²·K/W		N/A	Annex C	No
thermal resistance of unventilated air layer	$R_{tot;u}$		m²·K/W	-	0...0,23	Table 9	No
thermal resistance of ventilated air layer	$R_{tot;c}$		m²·K/W			Annex C	No
radiative coefficient for a black-body surface	h_{r0}		W/(m²·K)	5,1	-	Annex C	No
convective coefficient; internal surface	$h_{c;i}$		W/(m²·K)	-	0,7...5,0	Annex C	No
convective coefficient; external surface	$h_{c;e}$		W/(m²·K)	20	-	Annex C	No
radiative coefficient; internal surface	$h_{r;i}$		W/(m²·K)	4,59	-	Annex D	No
radiative coefficient; external surface	$h_{r;e}$		W/(m²·K)	5,13	-	Annex D	No
hemispherical emissivity of surface	ε	epsilon	-	0.9	-	Annex D	No

Table 8 lists identifiers for constants.

Table 8 — Identifiers for constants

Name	Symbol	Software name	Unit	Value	Range	Origin	Varying
Stefan-Boltzman constant	σ	sigma	W/(m²·K⁴)	5,67x10⁻⁸	-		No

Input data about products that are required for the calculation of thermal transmittance described in this International Standard shall be the data supplied by the manufacturer if they are declared according to relevant EN or EN ISO product standards (in the CEN area) or equivalent ISO or national standards (outside the CEN area).

Other input data, e.g. dimensional data of layers or components required for the calculation method described in this International Standard shall be acquired from the design of building elements with all details as specified in this International Standard.

6.4 Principles of the simplified calculation procedure

The principle of the calculation method is as follows:

a) obtain the thermal resistance of each thermally homogeneous or inhomogeneous part of the building element;

b) combine these individual resistances to obtain the total thermal resistance of the building element, including (where appropriate) the effect of surface resistances;

c) calculate the thermal transmittance as given in Clause 6.8;

d) corrections shall be applied to the thermal transmittance in accordance with Annex F if the total correction exceeds 3 % of the calculated thermal transmittance.

Thermal resistances of individual homogeneous layers of building element are obtained according to 6.7.1.1 and the total thermal resistance of the building element is calculated according to 6.7.1.2.

Thermal resistances of individual materials in inhomogeneous layers of a building element are obtained according to 6.7.1.1 and then used as arithmetic mean of the upper and lower limits of thermal resistance according to 6.7.2.2. The total thermal resistance of the building element is calculated according to 6.7.2.

The values of surface resistance given in 6.8 are appropriate in most cases. Annex C gives detailed procedures for low emissivity surfaces, specific external wind speeds and non-planar surfaces.

Air layers up to 0,3 m thickness 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 0. Annex D provides procedures for other cases.

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 6.10 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 C.

6.5 Thermal transmittance

6.5.1 By detailed calculation method

In the case of the detailed calculation method the thermal transmittance is the output from a calculation according to ISO 10211.

6.5.2 By simplified calculation method

In the case of the simplified calculation method the thermal transmittance is given by

$$U = \frac{1}{R_{tot}} \tag{1}$$

where

U is the thermal transmittance, in W/(m^2·K);

R_{tot} is the total thermal resistance, determined according to 6.7, in m^2·K/W.

Corrections shall be applied to the thermal transmittance, as appropriate, in accordance with Annex F. 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.

6.6 Thermal resistance

The thermal resistance of opaque component is given by

$$R_{c;op} = \frac{1}{U} - R_{si} - R_{se} \qquad (2)$$

where

$R_{c;op}$ is the thermal resistance of opaque component, in mText 2·K/W;

R_{si} is the thermal resistance of internal surface, in m^2·K/W;

R_{se} is the thermal resistance of external surface, in m^2·K/W;

U is the thermal transmittance, determined according to 6.5.

The surface resistances are the same as those used to calculate the thermal transmittance.

Formula (2) applies to the detailed method and to the simplified method.

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

6.7 Total thermal resistance

6.7.1 Thermal resistance of homogeneous components

6.7.1.1 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

$$R = \frac{d}{\lambda} \qquad (3)$$

where

R is the thermal resistance, in m^2·K/W;

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

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

Values of λ shall be calculated in accordance with ISO 10456 if based on measured data. In other cases λ is obtained from tabulated values.

A template for tabulated values is given in Table A.1, with an informative default list in Table B.1.

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 makes 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.

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

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

$$R_{tot} = R_{si} + R_1 + R_2 + ... + R_n + R_{se} \quad (4)$$

where

R_{tot}	is the total thermal resistance, in $m^2 \cdot K/W$;
R_{si}	is the internal surface resistance (see 6.8), in $m^2 \cdot K/W$;
R_1, R_2 ... R_n	are the design thermal resistances of each layer, in $m^2 \cdot K/W$;
R_{se}	is the external surface resistance (see 6.8), in $m^2 \cdot K/W$.

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.

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

6.7.2.1 Applicability

6.7.2.2 to 6.7.2.5 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 E.3.

NOTE 1 The method described in 6.7.2.2 to 6.7.2.5 is not suitable for computing surface temperatures for the purposes of evaluating the risk of condensation.

A template for other restrictions on the use of the simplified method is given in Table A.2, with a informative default choice in Table B.2.

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 6.7.2.2 to 6.7.2.5, 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 2 This is relevant when part of an element is sold as a separate item. Examples could include structural panels and voided masonry units.

6.7.2.2 Total thermal resistance of a component

The total thermal resistance, R_{tot}, 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:

$$R_{tot} = \frac{R_{tot;upper} + R_{tot;lower}}{2} \quad (5)$$

where

R_{tot}	is the total thermal resistance, in m²·K/W;
$R_{tot;upper}$	is the upper limit of the total thermal resistance, calculated in accordance with 6.7.2.3, in m²·K/W;
$R_{tot;lower}$	is the lower limit of the total thermal resistance, calculated in accordance with 6.7.2.4, in m²·K/W

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.

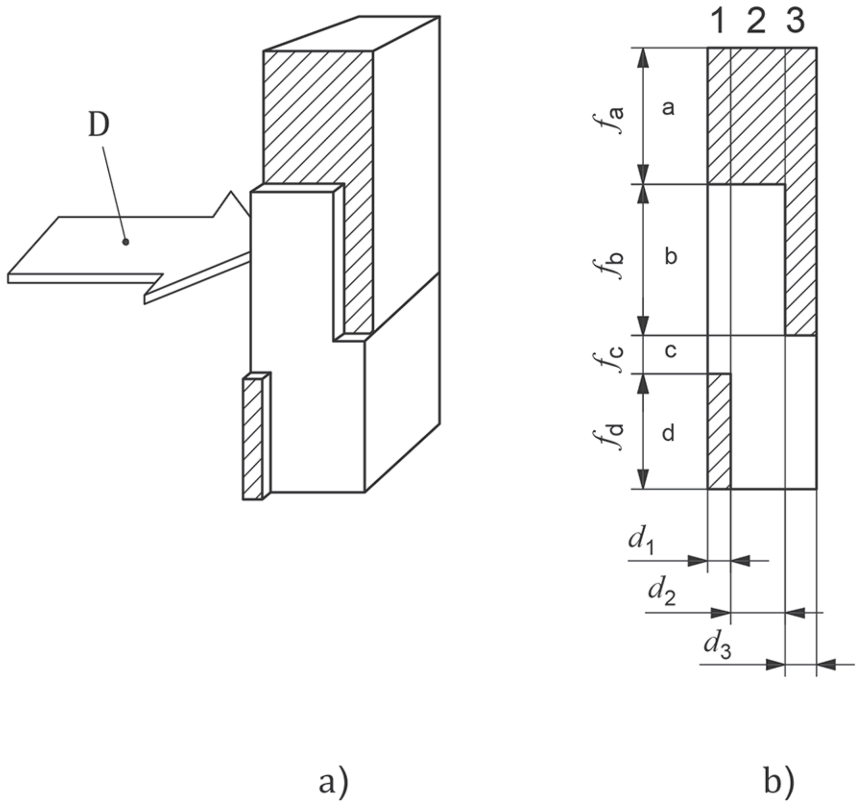
The component shown in Figure 1 a) is considered cut into sections a, b, c and d and into layers 1, 2 and 3 shown in Figure 1 b).

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

6.7.2.3 Upper limit of the total thermal resistance

The upper limit of the total thermal resistance, $R_{\text{tot;upper}}$, is determined by assuming one-dimensional heat flow perpendicular to the surfaces of the component. It is given by the following expression:

$$\frac{1}{R_{\text{tot;upper}}} = \frac{f_{\text{a}}}{R_{\text{tot;a}}} + \frac{f_{\text{b}}}{R_{\text{tot;b}}} + \ldots + \frac{f_{\text{q}}}{R_{\text{tot;q}}} \tag{6}$$

where

$R_{\text{tot;upper}}$ is the upper limit of the total thermal resistance, in m²·K/W;

$R_{\text{tot;a}}$, $R_{\text{tot;b}}$, ..., $R_{\text{tot;q}}$ are the total thermal resistances from environment to environment for each section, calculated using Formula (4), in m²·K/W;

f_{a}, f_{b}, ..., f_{q} are the fractional areas of each section.

6.7.2.4 Lower limit of the total thermal resistance

The lower limit of the total thermal resistance, $R_{\text{tot;lower}}$, is determined by assuming that all planes parallel to the surfaces of the component are isothermal surfaces.

If there is a non-planar surface adjacent to an air layer, the calculation is undertaken as if it were planar by considering:

a) the narrower sections extended (but without alteration to thermal resistance) shown in Figure 2:

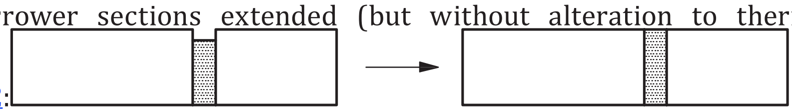


Figure 2 — Non-planar surface considered with narrower sections extended

b) or the projecting parts removed (so reducing the thermal resistance) shown in Figure 3:

Figure 3 — Non-planar surface considered with projecting parts removed

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

$$\frac{1}{R_j} = \frac{f_a}{R_{aj}} + \frac{f_b}{R_{bj}} + \ldots + \frac{f_q}{R_{qj}} \qquad (7)$$

where

R_j is an equivalent thermal resistance, in $m^2 \cdot K/W$;

$R_{a;j}$, $R_{b;j}$, ..., $R_{q;j}$ are the thermal resistance for each thermally inhomogeneous layer for each section, in $m^2 \cdot K/W$.

The lower limit is then determined using Formula (4).

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

$$R_j = \frac{d_j}{\lambda_{eq;j}} \qquad (8)$$

where the equivalent thermal conductivity $\lambda_{eq;j}$ of layer j is

$$\lambda_{eq;j} = \lambda_{aj} f_a + \lambda_{bj} f_b + \ldots + \lambda_{qj} f_q \qquad (9)$$

If an air layer is part of an inhomogeneous layer, it may be treated as a material with an equivalent thermal conductivity $\lambda_{eq;j} = d_j / R_g$, where R_g is the thermal resistance of the air layer determined in accordance with Annex D.

6.7.2.5 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.

A template specifying whether the maximum error is required is given in Table A.3, with an informative default choice in Table B.3.

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

$$e = \frac{R_{\text{tot;upper}} - R_{\text{tot;lower}}}{2 \times R_{\text{tot}}} \times 100 \tag{10}$$

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 6.7.2.5 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 6.7.2.2,

— the accuracy of the input data.

6.8 Surface resistances

Use the values in Table 9 for plane surfaces. 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 C.

Table 9 — Conventional surface resistances

Surface resistance	Direction of heat flow		
$m^2 \cdot K/W$	Upwards	Horizontal	Downwards
R_{si}	0,10	0,13	0,17
R_{se}	0,04	0,04	0,04
NOTE The surface resistances apply to surfaces in contact with air. No surface resistance applies to surfaces in contact with another material.			

The values given in Table 9 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, the values for horizontal heat flow shall be used.

A template specifying whether the procedures in Annex C shall be used for specific boundary conditions is given in Table A.4, with an informative default choice in Table B.4.

6.9 Thermal resistance of air layers

6.9.1 Applicability

The values given in 6.9.2 to 0 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 D.

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.

6.9.2 Unventilated air layer

An unventilated air layer is one in which there is no express provision for air flow through it. Values of thermal resistance are given in Table 10. 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 mmContinue-1 2 per metre of length (in the horizontal direction) for vertical air layers,

— 500 mmContinue-1 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 10 — Thermal resistance of unventilated air layers with high emissivity surfaces

Thickness of air layer	Thermal resistance $m^2 \cdot K/W$ 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 are obtained by linear interpolation.			

6.9.3 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 mmContinue-1 2 but < 1 500 mmContinue-1 2 per metre of length (in the horizontal direction) for vertical air layers;

— > 500 mmContinue-1 2 but < 1 500 mmContinue-1 2 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:

$$R_{tot} = \frac{1\,500 - A_v}{1\,000} R_{tot;nve} + \frac{A_v - 500}{1\,000} R_{tot;ve} \tag{11}$$

where

R_{tot} is the total thermal resistance, in $m^2 \cdot K/W$;

A_v is the area of openings, in m^2;

$R_{tot;nve}$ is the total thermal resistance with an unventilated air layer in accordance with 6.9.2, in $m^2 \cdot K/W$;

$R_{tot;ve}$ is the total thermal resistance with a well-ventilated air layer in accordance with 0, in $m^2 \cdot K/W$.

A template specifying whether this approximation is allowed is given in Table A.5, with an informative default choice in Table B.5.

6.9.4 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 mmContinue-1 2 per metre of length (in the horizontal direction) for vertical air layers;

— 1 500 mmContinue-1 2 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 C). Alternatively, the corresponding value of R_{si} from Table 9 may be used.

6.10 Thermal resistance of unheated spaces

6.10.1 General

The heat transfer from a building to the external environment via unheated spaces is calculated according to ISO 13789.

Alternatively, when the external envelope of the unheated space is not insulated, 6.10.2 and 0 provide simplified procedures, treating the unheated space as a thermal resistance.

A template specifying whether these simplified procedures are allowed is given in Table A.5, with an informative default choice in Table B.5.

NOTE 1 The procedures in ISO 13789 are more general and precise.

NOTE 2 For crawl spaces below suspended floors, see ISO 13370.

NOTE 3 The thermal resistances given in 6.10.2 and 6.10.3 are suitable for heat flow calculations, but not for calculations concerned with the hygrothermal conditions in the unheated space.

6.10.2 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 11.

Table 11 — 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 11 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.

6.10.3 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:

$$R_u = \frac{A_i}{\sum_k \left(A_{e;k} \; U_{e;k}\right) + 0{,}33 \times n \;\; V} \tag{12}$$

where

R_u is the thermal transmittance of unheated space, in m²·K/W;

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 shall be used.

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 Formula (12) is based on the procedure in ISO 13789 for the calculation of heat transfer through unheated spaces.

Annex A
(normative)

Template for input data and choices

A.1 Introduction

For the correct use of this International Standard Tables A.1 to A.5 form a template that shall be used to specify the choices between methods, required input data and calculation procedures.

NOTE 1 Default choices are provided in the informative Annex B.

NOTE 2 Following this template is necessary but not enough to guarantee consistency of data.

NOTE 3 In particular for the application within the context of EU Directives transposed into national legal requirements, these choices (either the default choices from Annex B or choices adapted to national/regional needs, but in any case following the template of this Annex) can be made available as National Annex or as separate (e.g. legal) document.

A.2 Thermal conductivity or thermal resistance values

See 6.7.1.1:

Table A.1 — Thermal conductivity or thermal resistance values

Material [a]	New buildings		Existing buildings	
	Thermal conductivity λ W/(m·K)	Thermal resistance R m^2·K/W	Thermal conductivity λ W/(m·K)	Thermal resistance R m^2·K/W

[a] Rows may be deleted or added and materials may be further specified or grouped

A.3 Choice of detailed or simplified method

See 5.2:

Table A.2 — Conditions for using simplified method

Item	Restrictions to use of simplified method
As imposed by 6.7.2.1?	Yes/No
If No, formulate the restrictions	Restrictions: .....

A.4 Estimation of error related to simplified method

See 6.7.2.5:

Table A.3 — Requirement to estimate maximum error of simplified method

Item	Choice
Maximum error on simplified error?	Yes/No
If Yes, maximum value of the error	…….. %

A.5 Surface resistances

See 6.8:

Table A.4 — Surface resistances for specific boundary conditions

Item	Choice
Use the procedures in Annex C for specific boundary conditions?	Yes/No
If yes, state conditions	

A.6 Other simplifications

See 6.9 and 6.10:

Table A.5 — Other simplifications

Item	Clause number	Choices
Allow approximation for slightly ventilated air layer according to 6.9	6.9	Yes/No
Allow simplified treatment of unheated spaces according to 6.10.2 or 6.10.3	6.10	Yes/No

A.7 Average precipitation

See F.4.2:

Table A.6 — Average precipitation

Item	Choices
Average rate of precipitation during heating season	Values in mm/day, which can be given for different locations

Annex B
(informative)

Default input data and choices

B.1 Introduction

Tables B.1 to B.5 have the same layout as the template in Annex A, but filled with default values and choices.

NOTE 1 In future versions of this International Standard some of the default values and choices will become mandatory.

NOTE 2 Using the default values will not guarantee consistency of data.

NOTE 3 In particular for the application within the context of EU Directives transposed into national legal requirements, these choices (or choices adapted to national/regional needs) can be made available as National Annex or as separate (e.g. legal) document, using the template in Annex A.

B.2 Thermal conductivity or thermal resistance values

Table B.1 — Thermal conductivity or thermal resistance values

Material	New buildings		Existing buildings	
	Thermal conductivity λ W/(m·K)	Thermal resistance R $m^2·K/W$	Thermal conductivity λ W/(m·K)	Thermal resistance R $m^2·K/W$
Materials with properties listed in ISO 10456	Values from ISO 10456			

B.3 Choice of detailed or simplified method

Table B.2 — Conditions for using simplified method

Item	Restrictions to use of simplified method
As imposed by 6.7.2.1?	Yes
If No, formulate the restrictions	-

B.4 Estimation of error related to simplified method

Table B.3 — Requirement to estimate maximum error of simplified method

Item	Choice
Maximum error on simplified error?	No

B.5 Surface resistances

Table B.4 — Surface resistances for specific boundary conditions

Item	Choice
Use the procedures in Annex C for specific boundary conditions	No

B.6 Other simplifications

Table B.5 — Other simplifications

Item	Clause number	Choices
Allow approximation for slightly ventilated air layer according to 6.9	6.9	Yes
Allow simplified treatment of unheated spaces according to 6.10.2 or 6.10.3	6.10	Yes

B.7 Average precipitation

Table B.6 — Average precipitation

Item	Choices
Average rate of precipitation during heating season	3 mm/day

Annex C
(normative)

Surface resistances

C.1 Plane surfaces

The surface resistance is given by Formula (C.1).

$$R_s = \frac{1}{h_c + h_r} \tag{C.1}$$

where

R_s is the surface resistance, in $m^2 \cdot K/W$;

h_c is the convective coefficient, in $W/(m^2 \cdot K)$;

h_r is the radiative coefficient, in $W/(m^2 \cdot K)$.

and

$$h_r = \varepsilon\, h_{r0} \tag{C.2}$$

$$h_{r0} = 4\, \sigma\, T_{mn}^{\ 3} \tag{C.3}$$

where

h_r is the radiative coefficient, in $W/(m^2 \cdot K)$;

ε is the hemispherical emissivity of the surface;

h_{r0} is the radiative coefficient for a black-body surface, in $W/(m^2 \cdot K)$;

σ is the Stefan-Boltzmann constant: $5{,}67 \times 10^{-8}$ $W/(m^2 \cdot K^4)$;

T_{mn} 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.

NOTE Formula (C.1) 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.

At internal surfaces, or external surfaces adjacent to a well-ventilated air layer (see 6.9.4),

$$h_c = h_{ci} \qquad (C.4)$$

Values of h_{ci} are given in Table C.1.

Table C.1 — Values of the convective surface coefficient, h_{ci}

Convective surface coefficient	Direction of heat flow		
$m^2 \cdot K/W$	**Upwards**	**Horizontal**	**Downwards**
h_{ci}	5,0	2,5	0,7

At external surfaces:

$$h_c = h_{ce} \qquad (C.5)$$

where

$$h_{ce} = 4 + 4v \qquad (C.6)$$

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

NOTE The values given in 6.8 for internal surface resistance are calculated for ε = 0,9 and with h_{r0} evaluated at 20 °C. The value given in 6.8 for external surface resistance is calculated for ε = 0,9, h_{r0} evaluated at 10 °C, and for v = 4 m/s.

C.2 Components with non-planar surfaces

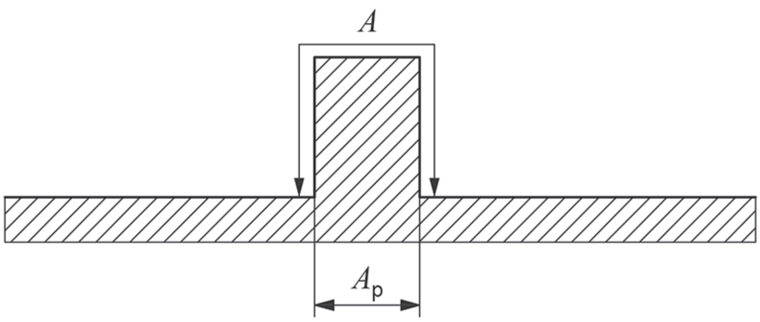
Parts which protrude from otherwise plane surfaces, such as structural columns, shall be disregarded in the calculation of the total thermal resistance if composed of material having a thermal conductivity not greater than 2,5 W/(m·K). If the part that protrudes is composed of material having a thermal 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 C.1):

$$R_{sp} = R_s \frac{A_p}{A} \qquad (C.7)$$

where

- R_{sp} is the surface resistance over the projected area of the protruding part, in $m^2 \cdot K/W$;
- R_s is the surface resistance of a plane component in accordance with B.1, in $m^2 \cdot K/W$;
- A_p is the projected area of the protruding part, in m^2;
- A is the actual surface area of the protruding part, in m^2.

Formula (C.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 C.1 — Actual and projected areas

Annex D
(normative)

Thermal resistance of airspaces

D.1 General

This annex applies to airspaces up to 0,3 m thickness 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.

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

The thermal resistance of an airspace is given by

$$R_a = \frac{1}{h_a + h_r} \quad \text{(D.1)}$$

where

R_a is the thermal resistance of the airspace, in m²·K/W;

h_a is the conduction/convection coefficient, in m²·K/W;

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

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 D.1 or Table D.2. In Tables D.1 and D.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 D.1 should be used when the temperature difference across the airspace is less than or equal to 5 K.

In the case of a roof construction in which the airspace is inclined at an angle α to the horizontal use an linearly interpolated intermediate value for h_a:

$$h_a = h_{a;0} + \left(h_{a;90} - h_{a;0}\right)\frac{\left(\alpha - 90\right)}{90} \qquad \text{(D.2)}$$

where

$h_{a;0}$ is the value from Table D.1 or Table D.2 for α = 0°, in W/(m²·K);

$h_{a;90}$ is the value for α = 90°, in W/(m²·K);

α inclination angle, in degrees.

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

Direction of heat flow	h_a [a] W/(m²·K)
Horizontal (α = 90°)	1,25
Upwards (α = 0°)	1,95
Downwards	$0,12 \times d^{-0,44}$
[a] Or, if larger, 0,025*d*.	

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

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

Direction of heat flow	h_a [a] W/(m²·K)
Horizontal (α = 90°)	$0,73 \times \left(” T\right)^{1/3}$
Upwards (α = 0°)	$1,14 \times \left(” T\right)^{1/3}$
Downwards	$0,09 \times \left(” T\right)^{0,187} d^{-0,44}$
[a] Or, if larger, 0,025/*d*.	

h_r is given by

$$h_r = E\, h_{r0} \qquad \text{(D.3)}$$

where

h_r is the radiative coefficient, in W/(m²·K);

E is the intersurface emittance;

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

and

$$E = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \quad \text{(D.4)}$$

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 9 in 6.9.2 are calculated using Formula (D.1) with h_a according to Table D.1, ε_1 = 0,9, ε_2 = 0,9, and h_{r0} evaluated at 10 °C.

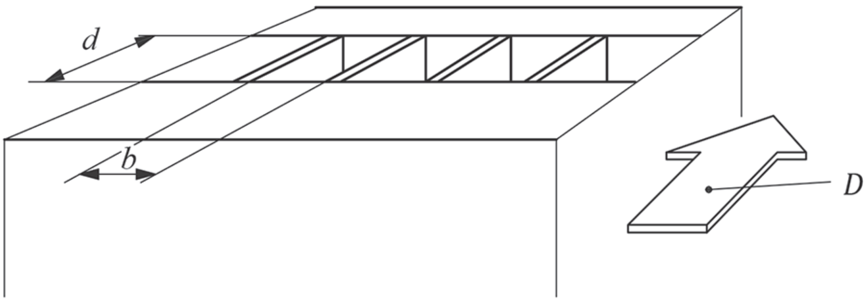
D.3 Ventilated airspaces with length and width both more than 10 times thickness

For a slightly ventilated airspace (as defined in 6.9.3), follow the procedure specified in 6.9.3.

For a well-ventilated airspace (as defined in 6.9.4), follow the procedure specified in 6.9.4.

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

Figure D.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 D.1 — Dimensions of small airspace

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

$$R_a = \frac{1}{h_a + h_r} \quad \text{(D.5)}$$

where

R_a is the thermal resistance of the airspace, in $m^2 \cdot K/W$;

$$h_r = \frac{h_{r0}}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 2 + \frac{2}{\left(1 + \sqrt{1 + d^2/b^2} - d/b\right)}} \tag{D.6}$$

where

h_r is the radiative coefficient, in W/(m^2·K);

h_{r0} is the radiative coefficient for a black-body surface (see C.1), in W/(m^2·K);

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 air-space.

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

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

NOTE 2 Formula (C.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 formula 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 E
(normative)

Calculation of the thermal transmittance of components with tapered layers

E.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 For tapered air layers, see D.1.

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

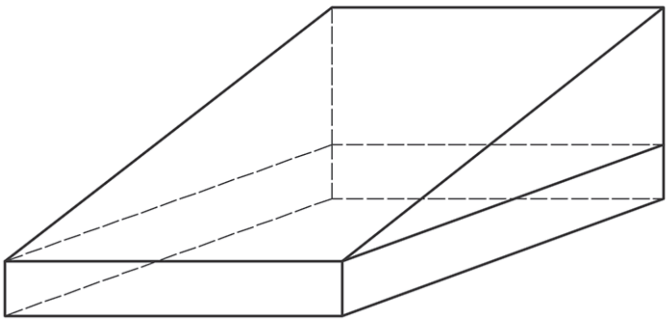


Figure E.1 — Principle of build-up of component

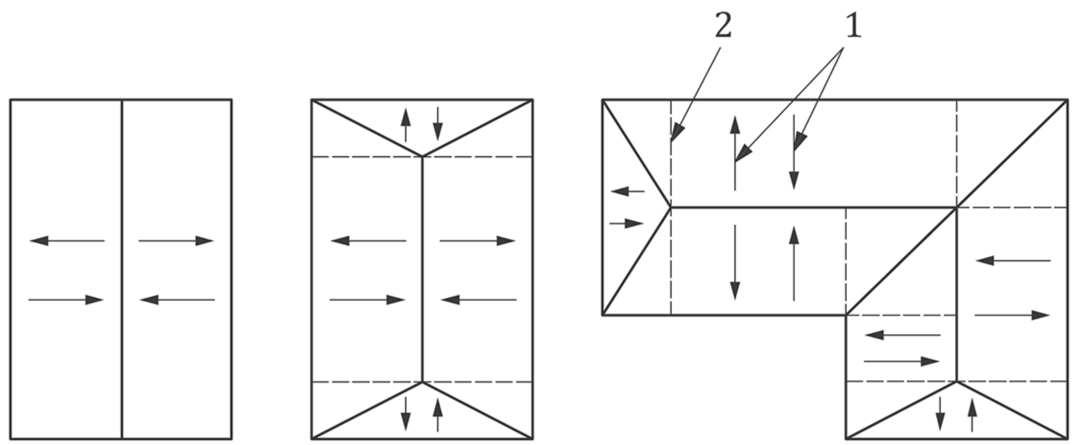
The thermal transmittance is defined by an integral over the area of the relevant component.

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 E.2.

In addition to the symbols listed in Clause 4, the symbols used in this annex are given in Table E.1:

Table E.1 — Symbols and unitsE.

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 Formulae (E.1) to (E.4)

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

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

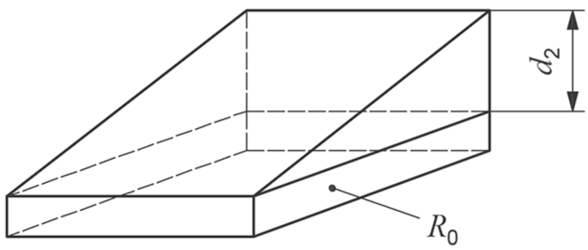
Use numerical methods for greater pitches.

E.2 Calculation for common shapes

E.2.1 Rectangular area

$$U = \frac{1}{R_2} \ln\left(1 + \frac{R_2}{R_0}\right) \tag{E.1}$$

where



U is the thermal transmittance, in W/(m²·K);

R_0 is the design thermal resistance of the remaining part, including surface resistances on both sides of the component, in m²·K/W;

R_2 is the maximum thermal resistance of the tapered layer, in m²·K/W.

Key

d_2 maximum thickness of the tapered layer

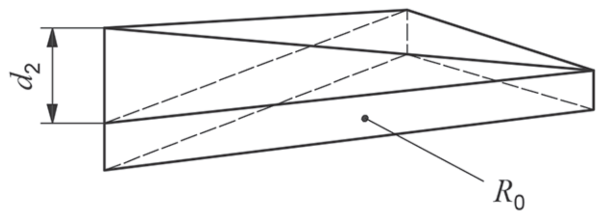
R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure E.3 — Rectangular area

E.2.2 Triangular area, thickest at apex

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

where



U is the thermal transmittance, in W/(m²·K);

R_0 is the design thermal resistance of the remaining part, including surface resistances on both sides of the component, in m²·K/W;

R_2 is the maximum thermal resistance of the tapered layer, in m²·K/W.

Key

d_2 maximum thickness of the tapered layer

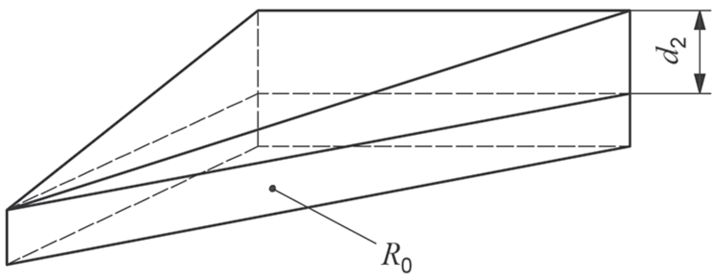
R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure E.4 — Triangular area, thickest at apex

E.2.3 Triangular area, thinnest at apex

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

where



U is the thermal transmittance, in W/(m²·K);

R_0 is the design thermal resistance of the remaining part, including surface resistances on both sides of the component, in m²·K/W;

R_2 is the maximum thermal resistance of the tapered layer, in m²·K/W.

Key

d_2 maximum thickness of the tapered layer

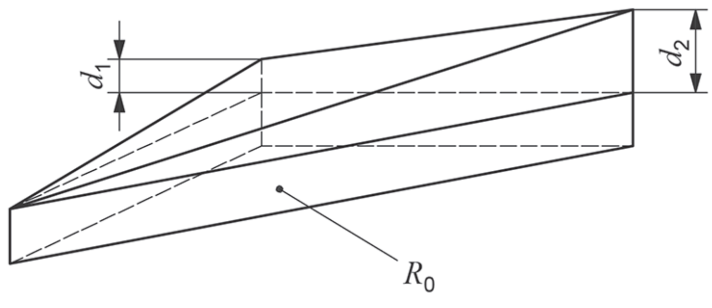
R_0 design thermal resistance of the remaining part, including surface resistances on both sides of the component

Figure E.5 — Triangular area, thinnest at apex

E.2.4 Triangular area, different thickness at each vertex

$$U = 2\left[\frac{R_0\, R_1 \ln\left(1+\frac{R_2}{R_0}\right) - R_0\, R_2 \ln\left(1+\frac{R_1}{R_0}\right) + R_1\, R_2 \ln\left(\frac{R_0+R_2}{R_0+R_1}\right)}{R_1\, R_2\left(R_2 - R_1\right)}\right] \tag{E.4}$$

where



U is the thermal transmittance, in W/(m²·K);

R_0 is the design thermal resistance of the remaining part, including surface resistances on both sides of the component, in m²·K/W;

R_1 is the intermediate thermal resistance of the tapered layer, in m²·K/W;

R_2 is the maximum thermal resistance of the tapered layer, in m²·K/W.

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 E.6 — Triangular area, different thickness at each vertex

E.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 Formula (4) if all layers are thermally homogeneous, or the procedure in 6.7.1 if there are inhomogeneous layers.

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

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

$$R_1 = \frac{d_1}{\lambda_t} \tag{E.5}$$

$$R_2 = \frac{d_2}{\lambda_t} \tag{E.6}$$

where

d_1 is the intermediate thickness of the tapered layer, in m;

d_2 is the maximum thickness of the tapered layer, in m;

R_1 is the intermediate thermal resistance of the tapered layer, in $m^2 \cdot K/W$;

R_2 is the maximum thermal resistance of the tapered layer, in $m^2 \cdot K/W$;

λ_t is the design thermal conductivity of the tapered part, in $W/(m \cdot K)$.

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

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

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

$$U = \frac{\sum U_i A_i}{\sum A_i} \tag{E.7}$$

where

d_1 is the intermediate thickness of the tapered layer, in m;

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

$$R_T = \frac{1}{U} \tag{E.8}$$

Annex F
(normative)

Correction to thermal transmittance

F.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:

$$U_c = U + \Delta U \tag{F.1}$$

ΔU is given by

$$\Delta U = \Delta U_g + \Delta U_f + \Delta U_r \tag{F.2}$$

where

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

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

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

F.2 Correction for air voids

F.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.

F.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 F.1).

Table F.1 — Corrections for air voids, C065708efig1.EPS

Level	Description	$\Delta U''$ W/(m²·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 Formula (F.3):

$$\varnothing U_g = \varnothing U'' \left(\frac{R_1}{R_{T,h}} \right)^2 \quad \text{(F.3)}$$

where

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

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

$\varnothing U''$ is given by Table F.1

F.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.

h) Examples of level 0 (correction $\varnothing U'' = 0$ 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.

— 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.

i) Examples of level 1 (correction $\varnothing U'' = 0,01$ 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.

j) Examples of level 2 (correction $\varnothing U'' = 0,04$ 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.

F.3 Correction for mechanical fasteners

F.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

$$\Delta U_{\mathrm{f}} = n_{\mathrm{f}}\ \chi \tag{F.4}$$

where

n_{f} is the number of fasteners per m^2

F.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

$$\Delta U_f = \alpha \frac{\lambda_f A_f n_f}{d_1} \left(\frac{R_1}{R_{T,h}} \right)^2 \tag{F.5}$$

where the coefficient α is given by

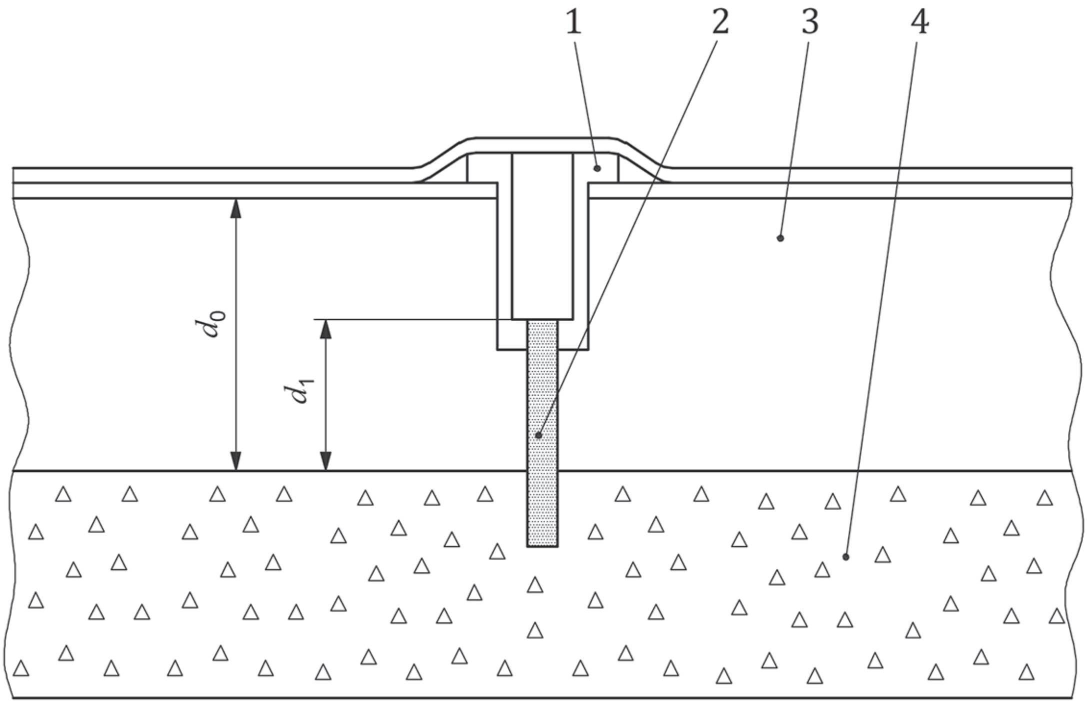
$\alpha = 0,8$ if the fastener fully penetrates the insulation layer,

$\alpha = 0,8 \times \frac{d_1}{d_0}$ in the case of a recessed fastener (see Figure f.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 m^2;
- 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;
- $R_{T,h}$ is the total thermal resistance of the component ignoring any thermal bridging, as obtained in 6.7.1, 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 F.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.

F.4 Correction procedure for inverted roofs

F.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).

F.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/(m2·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:

$$\varnothing U_{\mathrm{r}} = p\ f\ x \left(\frac{R_1}{R_{\mathrm{T}}} \right)^2 \tag{F.6}$$

where

- ΔU_{r} is the correction to the calculated thermal transmittance of the roof element, in W/(m^2·K);
- 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 drainage 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.

A template for average rate of precipitation is given in Table A.7, with a informative default choice in Table B.7.

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