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ISO 6946

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

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

Reference number
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Contents

Page

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 voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

ISO 6946 was prepared by the ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment,* Subcommittee SC 2, *Calculation methods*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

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

The changes in this third edition are mostly editorial. This document has been re-drafted according to CEN/TS 16629:2014.

Introduction

This document is part of a series aimed at the international harmonization of the methodology for assessing the energy performance of buildings. Throughout, this series is referred to as a “set of EPB standards”.

All EPB standards follow specific rules to ensure overall consistency, unambiguity and transparency.

All EPB standards provide a certain flexibility with regard to the methods, the required input data and references to other EPB standards, by the introduction of a normative template in Annex A and Annex B with informative default choices.

For the correct use of this document, a normative template is given in Annex A to specify these choices. Informative default choices are provided in Annex B.

The main target groups for this document are architects, engineers and regulators.

Use by or for regulators: In case the document is used in the context of national or regional legal requirements, mandatory choices may be given at national or regional level for such specific applications. These choices (either the informative default choices from Annex B or choices adapted to national/regional needs, but in any case following the template of Annex A) can be made available as national annex or as separate (e.g. legal) document (national data sheet).

NOTE 1 So in this case:

— the regulators will specify the choices;

— the individual user will apply the document to assess the energy performance of a building, and thereby use the choices made by the regulators.

Topics addressed in this document can be subject to public regulation. Public regulation on the same topics can override the default values in Annex B. Public regulation on the same topics can even, for certain applications, override the use of this document. Legal requirements and choices are in general not published in standards but in legal documents. In order to avoid double publications and difficult updating of double documents, a national annex may refer to the legal texts where national choices have been made by public authorities. Different national annexes or national data sheets are possible, for different applications.

It is expected, if the default values, choices and references to other EPB standards in Annex B are not followed due to national regulations, policy or traditions, that:

— national or regional authorities prepare data sheets containing the choices and national or regional values, according to the model in Annex A. In this case a national annex (e.g. NA) is recommended, containing a reference to these data sheets;

— or, by default, the national standards body will consider the possibility to add or include a national annex in agreement with the template of Annex A, in accordance to the legal documents that give national or regional values and choices.

Further target groups are parties wanting to motivate their assumptions by classifying the building energy performance for a dedicated building stock.

More information is provided in the Technical Report (ISO/TR 52019-2)[1] accompanying this document.

The subset of EPB standards prepared under the responsibility of ISO/TC 163/SC 2 cover *inter alia*:

— calculation procedures on the overall energy use and energy performance of buildings;

— calculation procedures on the internal temperature in buildings (e.g. in case of no space heating or cooling);

— indicators for partial EPB requirements related to thermal energy balance and fabric features;

— 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 technical committees for the details on appliances, technical building systems, indoor environment, etc.

This document 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.

This document provides calculation methods for the thermal transmittance of walls and roofs

— to allow comparisons between different constructions,

— to help in judging compliance with regulations, and

— to provide input data for calculation of annual energy use for heating or cooling buildings.

Table 1 shows the relative position of this document within the set of EPB standards in the context of the modular structure as set out in ISO 52000-1.

NOTE 2 In ISO/TR 52000-2, the same table can be found, with, for each module, the numbers of the relevant EPB standards and accompanying technical reports that are published or in preparation.

NOTE 3 The modules represent EPB standards, although one EPB standard could cover more than one module and one module could be covered by more than one EPB standard, for instance, a simplified and a detailed method, respectively. See also Clause 2 and Tables A.1 and B.1.

Table 1 — Position of this document (*in casu* M2–5) within the modular structure of the set of EPB standards

	Overarching		**Building (as such)**		**Technical Building Systems**									
Sub module	**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								a	
3	Applications		(Free) indoor conditions without systems		Maximum load and power									

a The shaded modules are not applicable.

	Overarching		Building (as such)		Technical Building Systems										
Sub module	**Descriptions**		**Descrip-tions**		**Descrip-tions**	**Heat-ing**	**Cool-ing**	**Venti-lation**	**Hu-midifi-cation**	**Dehu-midifi-cation**	**Do-mestic hot water**	**Light-ing**	**Building automa-tion and control**	**PV, wind, ..**
sub1		**M1**		**M2**		**M3**	**M4**	**M5**	**M6**	**M7**	**M8**	**M9**	**M10**	**M11**
4	Ways to ex-press energy performance		Ways to ex-press energy performance		Ways to express energy perfor-mance									
5	Building categories and building boundaries		Heat transfer by transmis-sion	ISO 6946	Emission and control									
6	Building occupancy and operating conditions		Heat transfer by infiltra-tion and ventilation		Distribu-tion and control									
7	Aggregation of energy services and energy carriers		Internal heat gains		Storage and control									
8	Building zoning		Solar heat gains		Generation and control									
9	Calculated energy per-formance		Building dynamics (thermal mass)		Load dispatch-ing and operating conditions									
10	Measured energy per-formance		Measured energy per-formance		Measured energy perfor-mance									
11	Inspection		Inspection		Inspection									

[a] The shaded modules are not applicable.

Table 1 *(continued)*

	Overarching		Building (as such)		Technical Building Systems									
Sub module	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
12	Ways to express indoor comfort				BMS									
13	External environment conditions													
14	Economic calculation													

[a] The shaded modules are not applicable.

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

1 Scope

This document 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 document 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 document.

NOTE Table 1 in the Introduction shows the relative position of this document within the set of EPB standards in the context of the modular structure as set out in ISO 52000-1.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements 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*

ISO 52000-1:2017, *Energy performance of buildings — Overarching EPB assessment — Part 1: General framework and procedures*

NOTE 1 Default references to EPB standards other than ISO 52000-1 are identified by the EPB module code number and given in Annex A (normative template in Table A.1) and Annex B (informative default choice in Table B.1).

EXAMPLE EPB module code number: M5–5, or M5–5,1 (if module M5–5 is subdivided), or M5–5/1 (if reference to a specific clause of the standard covering M5–5).

NOTE 2 In this document, there are no choices in references to other EPB standards. The sentence and note above is kept to maintain uniformity between all EPB standards.

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, ISO 52000-1 and the following apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

3.1
building element
major part of a building

EXAMPLE Wall, floor or roof.

3.2
building component
building element or a part of it

Note 1 to entry: In this document, 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, for example, ageing, moisture and/or convection. In contrast to the declared value which is 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
EPB standard
standard that complies with the requirements given in ISO 52000-1, CEN/TS 16628[3] and CEN/TS 16629[4]

Note 1 to entry: These three basic EPB documents were developed under a mandate given to CEN by the European Commission and the European Free Trade Association and support essential requirements of EU Directive 2010/31/EU on the energy performance of buildings. Several EPB standards and related documents are developed or revised under the same mandate.

[SOURCE: ISO 52000-1:2017, 3.5.14]

3.7
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 document, the symbols given in ISO 52000-1 and the following apply.

Symbol	Quantity	Unit
A	area	m^2
d	thickness	m
h	surface coefficient of heat transfer	$W/(m^2 \cdot K)$
n	ventilation rate	1/h
R	thermal resistance	$m^2 \cdot K/W$
U	thermal transmittance	$W/(m^2 \cdot K)$
V	volume	m^3
λ	design thermal conductivity	$W/(m \cdot K)$

4.2 Subscripts

For the purposes of this document, the subscripts given in ISO 52000-1 and the following apply.

Subscript	Identification
a	air
c	component
eq	equivalent
e	external
f	mechanical fasteners
g	air voids
nve	not ventilated
op	opaque
r	inverted roofs
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, ventilation

5 Description of the method

5.1 Output

The output of this document 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 on the whole building element or on a representative part of it. The modelling rules shall be in accordance with those in ISO 10211. This method is valid for any building component.

5.4 Simplified calculation method

The simplified calculation method is described in Clause 6. 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 2.

Table 2 — Output data

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

6.2 Calculation time intervals

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, so there is no need to consider a specific time interval.

6.3 Input data

Tables 3, 4 and 5 list identifiers for input data required for the calculation.

Table 3 — Identifiers for geometric characteristics

Name	Symbol	Unit	Value	Range	Origin	Varying
area	A	m^2	—	>0	—	No
thickness of material layer	d	m	—	>0	—	No

Table 4 — Identifiers for thermal characteristics of a building component

Name	Symbol	Unit	Value	Range	Origin	Varying
design thermal conductivity	λ	W/(m·K)	—	0 to 200	ISO 10456	No

Table 5 — Identifiers for tabulated and conventional values

Name	Symbol	Unit	Value	Range	Origin	Varying
external surface resistance	R_{se}	$m^2 \cdot K/W$	0,04	—	6.8	No
internal surface resistance	R_{si}	$m^2 \cdot K/W$	—	0,1 to 0,2	6.8	No
thermal resistance of unheated spaces	R_u	$m^2 \cdot K/W$	—	0,06 to 0,3	6.10	No
thermal resistance of air layer	R_a	$m^2 \cdot K/W$	—	—	6.9	No
thermal resistance of unventilated air layer	$R_{tot;u}$	$m^2 \cdot K/W$	—	0 to 0,23	6.9	No
thermal resistance of ventilated air layer	$R_{tot;c}$	$m^2 \cdot K/W$	—	—	6.9	No
radiative coefficient for a black-body surface	h_{r0}	$W/(m^2 \cdot K)$	5,1	—	Annex C	No
convective coefficient; internal surface	$h_{c;i}$	$W/(m^2 \cdot K)$	—	0,7 to 5,0	Annex C	No
convective coefficient; external surface	$h_{c;e}$	$W/(m^2 \cdot K)$	20	—	Annex C	No
radiative coefficient; internal surface	$h_{r;i}$	$W/(m^2 \cdot K)$	4,59	—	Annex D	No
radiative coefficient; external surface	$h_{r;e}$	$W/(m^2 \cdot K)$	5,13	—	Annex D	No
hemispherical emissivity of surface	ε	—	0,9	—	Annex D	No

Table 6 gives the identifier for a constant.

Table 6 — Identifier for constant

Name	Symbol	Unit	Value	Range	Origin	Varying
Stefan-Boltzmann constant	σ	$W/(m^2 \cdot K^4)$	$5,67 \times 10^{-8}$	—	—	No

Input data about products that are required for the calculation of thermal transmittance described in this document 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 document, shall be acquired from the design of building elements with all details as specified in this document.

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 6.5.2;

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 document. Values of the thermal resistance of large unventilated air layers with high emissivity surfaces are given in 6.9.2. 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 is 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:

$$U = \frac{1}{R_{tot}} \quad (1)$$

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 to the thermal transmittance, as appropriate to the building element concerned, shall be calculated in accordance with Annex F. If, however, the total correction as obtained by Formula (F.2) 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 the component is given by:

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

where

$R_{c;op}$ is the thermal resistance of the component, in $m^2 \cdot K/W$;

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

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

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.

NOTE $R_{c;op}$ is the thermal resistance of the component from surface to surface, without surface resistances.

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

$$R = \frac{d}{\lambda} \tag{3}$$

where

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

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

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

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, see ISO 10456.

A template for tabulated values is given in Table A.2, with an informative default list in Table B.2.

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:

$$R_{tot} = R_{si} + R_1 + R_2 + \dots + R_n + R_{se} \tag{4}$$

where

R_{tot} is the total thermal resistance, in m²·K/W;

R_{si} is the internal surface resistance (see 6.8), in m²·K/W;

$R_1, R_2 \dots R_n$ are the design thermal resistances of each layer, in m²·K/W;

R_{se} is the external surface resistance (see 6.8), in m²·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 F.3.

NOTE 1 A more precise result is obtained by using the detailed method in 5.3. 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 6.7.2.2 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.3, with an informative default choice in Table B.3.

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

6.7.2.2 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:

$$R_{tot} = \frac{R_{tot;upper} + R_{tot;lower}}{2} \tag{5}$$

where

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

$R_{tot;upper}$ 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 $m^2 \cdot K/W$.

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.

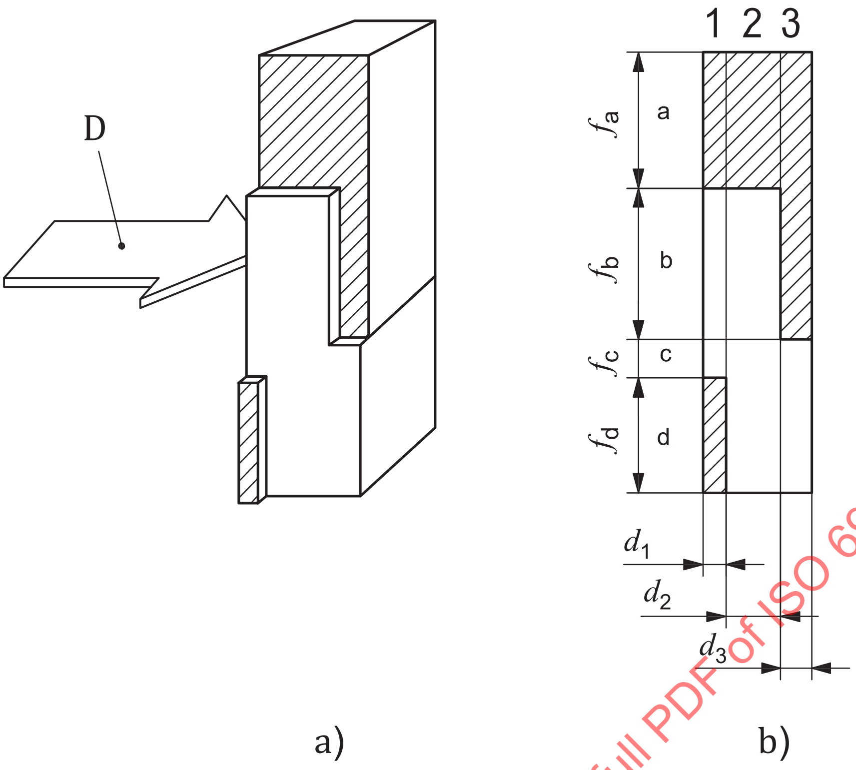
The component shown in Figure 1 a) is considered cut into sections a, b, c and d and into layers 1, 2 and 3 shown in Figure 1 b).

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, $f_a + f_b + ... + f_q = 1$.



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

$$\frac{1}{R_{tot;upper}} = \frac{f_a}{R_{tot;a}} + \frac{f_b}{R_{tot;b}} + \ldots + \frac{f_q}{R_{tot;q}} \qquad (6)$$

where

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

$R_{tot;a}$, $R_{tot;b}$,..., $R_{tot;q}$ 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, $R_{tot;lower}$, 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.

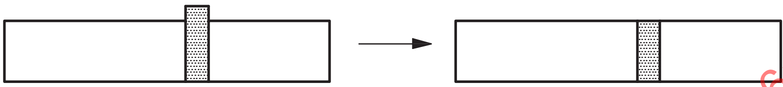


Figure 3 — Non-planar surface considered with projecting parts removed

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

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

where

R_j is an equivalent thermal resistance, in m²·K/W;

R_{aj}, R_{bj}, ... , R_{qj} are the thermal resistance for each thermally inhomogeneous layer for each section, in m²·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:

$$R_j = \frac{d_j}{\lambda_{eq;j}} \tag{8}$$

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

$$\lambda_{eq;j} = \lambda_{aj} \cdot f_a + \lambda_{bj} \cdot f_b + \ldots + \lambda_{qj} \cdot f_q \tag{9}$$

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.4, with an informative default choice in Table B.4.

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

$$e = \frac{R_{\text{tot;upper}} - R_{\text{tot;lower}}}{2 \cdot R_{\text{tot}}} \cdot 100 \qquad (10)$$

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, and

— the accuracy of the input data.

6.8 Surface resistances

Use the values in Table 7 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 C.

Table 7 — Conventional surface resistances

Surface resistance m²·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 surface resistances apply to surfaces in contact with air. No surface resistance applies to surfaces in contact with another material.

NOTE 2 The values for internal surface resistance are calculated for ε = 0,9 and with h_{r0} evaluated at 20 °C. The value for external surface resistance is calculated for ε = 0,9, h_{r0} evaluated at 10 °C, and for v = 4 m/s.

See 6.9.4 for R_{se} in the case of a component containing a well-ventilated air layer.

The values given in Table 7 are design values. In cases where values independent of heat flow direction are required, e.g. the declaration of the thermal transmittance of components, 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.5, with an informative default choice in Table B.5.

6.9 Thermal resistance of air layers

6.9.1 Applicability

The values given in 6.9.2 to 6.9.4 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, and

— 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 8. 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, and

— 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 8 — Thermal resistance of unventilated air layers with high emissivity surfaces

Thickness of air layer	Thermal resistance m^2·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_{ve}, within the following ranges:

— >500 mm^2 but <1 500 mm^2 per metre of length (in the horizontal direction) for vertical air layers;

— >500 mm^2 but <1 500 mm^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:

$$R_{\text{tot}} = \frac{\left(1\,500 - A_{\text{ve}}\right)}{1\,000} \cdot R_{\text{tot;nve}} + \frac{\left(A_{\text{ve}} - 500\right)}{1\,000} \cdot R_{\text{tot;ve}} \tag{11}$$

where

R_{tot} is the total thermal resistance, in m²·K/W;

A_{ve} is the area of openings, in m²;

$R_{\text{tot;nve}}$ is the total thermal resistance with an unventilated air layer in accordance with 6.9.2, in m²·K/W;

$R_{\text{tot;ve}}$ is the total thermal resistance with a ventilated air layer in accordance with 6.9.4, in m²·K/W.

A template specifying whether this approximation is allowed is given in Table A.6, with an informative default choice in Table B.6.

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 mm² per metre of length (in the horizontal direction) for vertical air layers, and

— 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 C). Alternatively, the corresponding value of R_{si} from Table 7 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 6.10.3 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.6, with an informative default choice in Table B.6.

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 9.

Table 9 — Thermal resistance of roof spaces

	Characteristics of roof	R_u $m^2 \cdot K/W$
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 9 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:

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

where

R_u is the thermal resistance of unheated space, in $m^2 \cdot K/W$;

A_i is the total area of all elements between the internal environment and the unheated space, in m^2;

$A_{e;k}$ is the area of element k between the unheated space and the external environment, in m^2;

$U_{e;k}$ is the thermal transmittance of element k between the unheated space and the external environment, in $W/(m^2 \cdot K)$;

0,33 is the value of the thermal capacity of air, in $Wh/(m^3 \cdot K)$;

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

V is the volume of the unheated space, in m^3;

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 $W/(m^2 \cdot K)$ 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)

Input and method selection data sheet — Template

A.1 General

The template in Annex A of this document shall be used to specify the choices between methods, the required input data and references to other documents.

NOTE 1 Following this template is not enough to guarantee consistency of data.

NOTE 2 Informative default choices are provided in Annex B. Alternative values and choices can be imposed by national/regional regulations. If the default values and choices of Annex B are not adopted because of the national/regional regulations, policies or national traditions, it is expected that:

— national or regional authorities prepare data sheets containing the national or regional values and choices, in line with the template in Annex A; or

— by default, the national standards body will add or include a national annex (Annex NA) to this document, in line with the template in Annex A, giving national or regional values and choices in accordance with their legal documents.

NOTE 3 The template in Annex A is applicable to different applications (e.g., the design of a new building, certification of a new building, renovation of an existing building and certification of an existing building) and for different types of buildings (e.g., small or simple buildings and large or complex buildings). A distinction in values and choices for different applications or building types could be made:

— by adding columns or rows (one for each application), if the template allows;

— by including more than one version of a table (one for each application), numbered consecutively as a, b, c, ... For example: Table NA.3a, Table NA.3b;

— by developing different national/regional data sheets for the same standard. In case of a national annex to the standard these will be consecutively numbered (Annex NA, Annex NB, Annex NC, ...).

NOTE 4 In the section "Introduction" of a national/regional data sheet information can be added, for example about the applicable national/regional regulations.

NOTE 5 For certain input values to be acquired by the user, a data sheet following the template of Annex A, could contain a reference to national procedures for assessing the needed input data. For instance, reference to a national assessment protocol comprising decision trees, tables and pre-calculations.

The shaded fields in the tables are part of the template and consequently not open for input.

A.2 References

The references, identified by the module code number, are given in Table A.1.

Table A.1 — References

Reference	Reference document[a]	
	Number	Title
Mx-y[b]	...	...
	...	...

[a] If a reference comprises more than one document, the references may be differentiated.

[b] In this document, there are no choices in references to other EPB standards. The table is kept to maintain uniformity between all EPB standards.

A.3 Selection of methods

In this document, there is no need to specify choices in methods. A.3 is kept to maintain uniformity between all EPB standards.

A.4 Input data and choices

Table A.2 — Thermal conductivity or thermal resistance values (see 6.7.1.1)

Material[a]	New buildings	Existing buildings
	Thermal conductivity λ W/(m·K)	Thermal conductivity λ W/(m·K)
Material or construction[a]	**Thermal resistance** R m²·K/W	**Thermal resistance** R m²·K/W

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

Table A.3 — Conditions for using simplified method (see 5.2)

Item	Restrictions to use of simplified method
Simplified method	Restrictions: .....

Table A.4 — Requirement to estimate maximum error of simplified method (see 6.7.2.5)

Item	Choice
Maximum error for simplified method?	Yes/No
If yes, maximum value of the error	.... %

Table A.5 — Surface resistances for specific boundary conditions (see 6.8)

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

Table A.6 — Other simplifications (see 6.9 and 6.10)

Item	Clause number	Choices
Allow approximation for slightly ventilated air layer according to 6.9.3	6.9	Yes/No
Allow simplified treatment of unheated spaces according to 6.10.2 or 6.10.3	6.10	Yes/No

Table A.7 — Average precipitation (see F.4.2)

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

Annex B
(informative)

Input and method selection data sheet — Default choices

B.1 General

The template in Annex A of this document shall be used to specify the choices between methods, the required input data and references to other documents.

NOTE 1 Following this template is not enough to guarantee consistency of data.

NOTE 2 Informative default choices are provided in Annex B. Alternative values and choices can be imposed by national/regional regulations. If the default values and choices of Annex B are not adopted because of the national/regional regulations, policies or national traditions, it is expected that:

— national or regional authorities prepare data sheets containing the national or regional values and choices, in line with the template in Annex A; or

— by default, the national standards body will add or include a national annex (Annex NA) to this document, in line with the template in Annex A, giving national or regional values and choices in accordance with their legal documents.

NOTE 3 The template in Annex A is applicable to different applications (e.g., the design of a new building, certification of a new building, renovation of an existing building and certification of an existing building) and for different types of buildings (e.g., small or simple buildings and large or complex buildings). A distinction in values and choices for different applications or building types could be made:

— by adding columns or rows (one for each application), if the template allows;

— by including more than one version of a table (one for each application), numbered consecutively as a, b, c, ... For example: Table NA.3a, Table NA.3b;

— by developing different national/regional data sheets for the same standard. In case of a national annex to the standard these will be consecutively numbered (Annex NA, Annex NB, Annex NC, ...).

NOTE 4 In the section "Introduction" of a national/regional data sheet information can be added, for example about the applicable national/regional regulations.

NOTE 5 For certain input values to be acquired by the user, a data sheet following the template of Annex A, could contain a reference to national procedures for assessing the needed input data. For instance, reference to a national assessment protocol comprising decision trees, tables and pre-calculations.

The shaded fields in the tables are part of the template and consequently not open for input.

B.2 References

The references, identified by the module code number, are given in Table B.1.

Table B.1 — References

Reference	Reference document[a]	
	Number	Title
Mx-y[b]	...	...
	...	...

[a] If a reference comprises more than one document, the references may be differentiated.

[b] In this document, there are no choices in references to other EPB standards. The table is kept to maintain uniformity between all EPB standards.

B.3 Selection of methods

In this document, there is no need to specify choices in methods. B.3 is kept to maintain uniformity between all EPB standards.

B.4 Input data and choices

Table B.2 — Thermal conductivity or thermal resistance values (see 6.7.1.1)

Material[a]	New buildings	Existing buildings
	Thermal conductivity λ W/(m·K)	Thermal conductivity λ W/(m·K)
Materials with properties in ISO or EN product standard or listed in ISO 10456	Values according to product standard if available, otherwise from ISO 10456	
Material or construction[a]	**Thermal resistance R m²·K/W**	**Thermal resistance R m²·K/W**
Materials or constructions with properties in ISO or EN product standard or listed in ISO 10456	Values according to product standard if available, otherwise from ISO 10456	

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

Table B.3 — Conditions for using simplified method (see 5.2)

Item	Restrictions to use of simplified method
Simplified method	As stated in 6.7.2.1

Table B.4 — Requirement to estimate maximum error of simplified method (see 6.7.2.5)

Item	Choice
Maximum error for simplified method?	No

Table B.5 — Surface resistances for specific boundary conditions (see 6.8)

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

Table B.6 — Other simplifications (see 6.9 and 6.10)

Item	Clause number	Choices
Allow approximation for slightly ventilated air layer according to 6.9.3	6.9	Yes
Allow simplified treatment of unheated spaces according to 6.10.2 or 6.10.3	6.10	Yes

Table B.7 — Average precipitation (see F.4.2)

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

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

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

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.

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):

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

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:

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

where

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

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

NOTE Conventional values for the surface resistances are given in 6.8.

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):

$$R_{sp} = R_s \cdot \frac{A_p}{A} \tag{C.7}$$

where

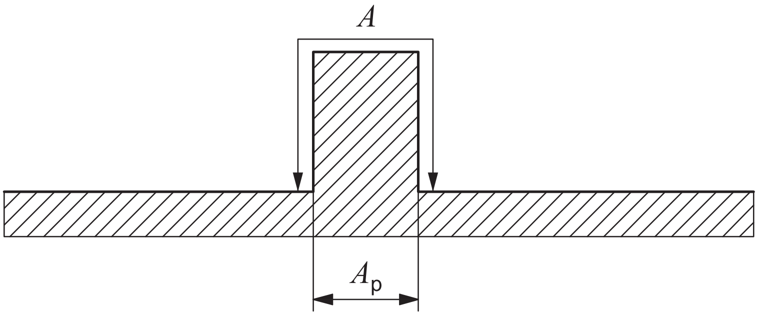
R_{sp} is the surface resistance over the projected area of the protruding part, in $m^2 \cdot K/W$;

R_s is the surface resistance of a plane component in accordance with C.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:

$$R_a = \frac{1}{h_a + h_r} \tag{D.1}$$

where

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

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

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 document, 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 a linearly interpolated intermediate value for h_a:

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

where

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

$h_{a;90}$ is the value from Table D.1 or Table D.2 for $\alpha = 90°$, in W/(m²·K);

α is the inclination angle of the air space with respect to the horizontal, 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 than value from table, 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°)	$0{,}73 \times \left(\Delta T\right)^{1/3}$
Upwards (α = 0°)	$1{,}14 \times \left(\Delta T\right)^{1/3}$
Downwards	$0{,}09 \times \left(\Delta T\right)^{0{,}187} d^{-0{,}44}$

[a] Or, if larger than value from table, 0,025/d.

h_r is given by

$$h_r = E \cdot h_{r0} \tag{D.3}$$

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

$$E = \frac{1}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} \tag{D.4}$$

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 10 in 6.9.2 are calculated using Formula (D.1) with h_a according to Table D.1. $\varepsilon_1 = 0{,}9$, $\varepsilon_2 = 0{,}9$, and h_{r0} evaluated at 10 °C.

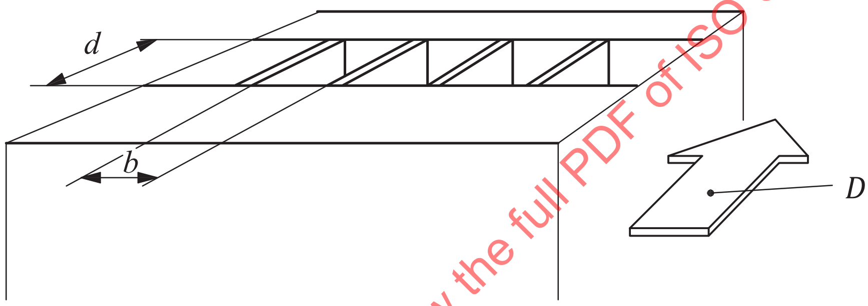
D.3 Ventilated airspaces with length and width both more than 10 times thickness

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:

$$R_a = \frac{1}{h_a + h_r} \tag{D.5}$$

where

R_a is the thermal resistance of the airspace, in m²·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, in m;

b is the width of the airspace, in m;

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 D.2.

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

NOTE 2 Formula (D.5) 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, Formula (D.5) 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.

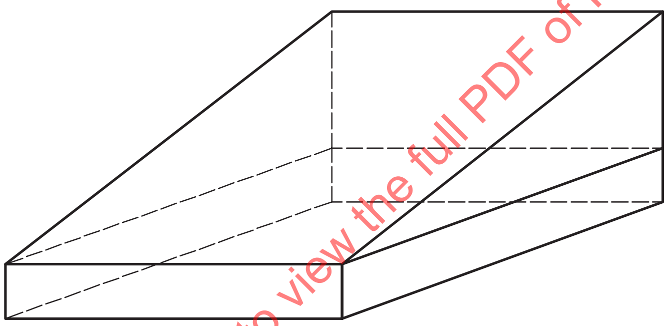


Figure E.1 — Principle of build-up of component

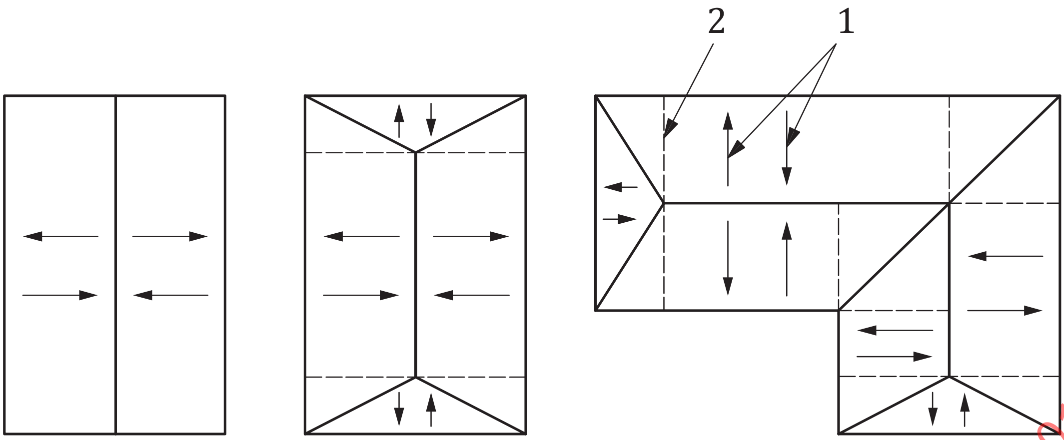
The thermal transmittance is defined by an integral over the area of the relevant component.

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 units

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	m²·K/W
R_1	intermediate thermal resistance of the tapered layer	m²·K/W
R_2	maximum thermal resistance of the tapered layer	m² 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

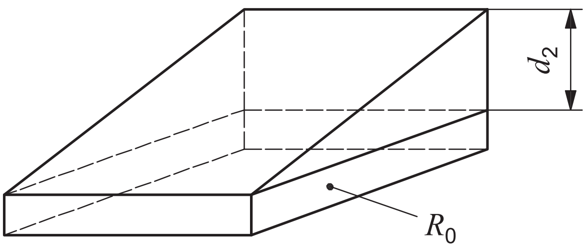
$$U = \frac{1}{R_2} \cdot \ln\left(1 + \frac{R_2}{R_0}\right) \tag{E.1}$$

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

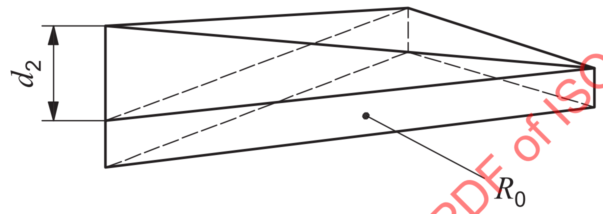
$$U = \frac{2}{R_2} \cdot \left[\left(1 + \frac{R_0}{R_2}\right) \cdot \ln\left(1 + \frac{R_2}{R_0}\right) - 1 \right] \tag{E.2}$$

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

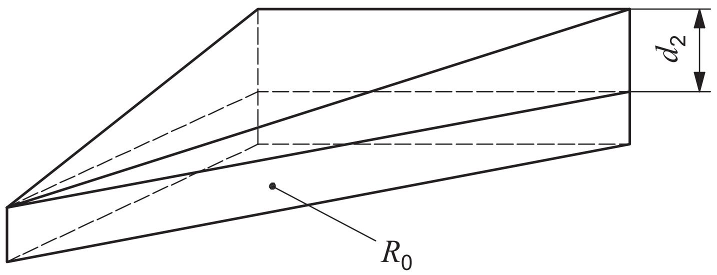
$$U = \frac{2}{R_2} \cdot \left[1 - \frac{R_0}{R_2} \cdot \ln\left(1 + \frac{R_2}{R_0}\right) \right] \tag{E.3}$$

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

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

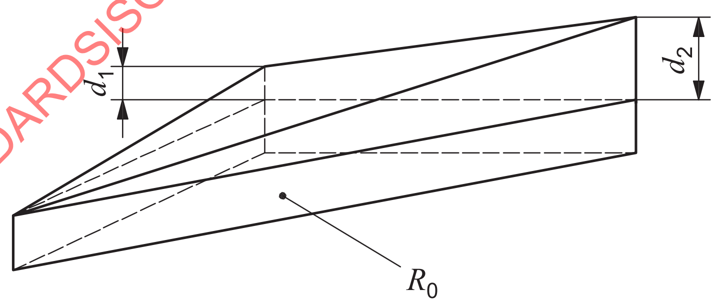
where

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