
**Thermal performance of windows,
doors and shutters — Calculation of
thermal transmittance —**

**Part 2:
Numerical method for frames**

*Performance thermique des fenêtres, portes et fermetures — Calcul
du coefficient de transmission thermique —*

Partie 2: Méthode numérique pour les encadrements





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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 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 10077-2 was prepared by the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components*, in collaboration with ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in accordance with the agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This third edition cancels and replaces the second edition (ISO 10077-2:2012), which has been technically revised to comply with the requirements for the EPB set of standards. It also incorporates the Technical Corrigendum ISO 10077-2:2012/Cor 1:2012.

In addition, [Clause 6](#) has been technically revised by

- adding a new approach for the treatment of cavities,
- separating conduction/convection and radiation, and
- introducing the radiosity method.

[Annex H](#) and [Annex G](#) were also added.

A list of all parts in the ISO 10077 series can be found on the ISO website.

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 ISO 52000-1 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 this [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](#) of this document. 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 52022-2) accompanying this document.

The framework for overall EPB includes:

- a) common terms, definitions and symbols;
- b) building and assessment boundaries;
- c) building partitioning into space categories;

- d) methodology for calculating the EPB (formulae on energy used, delivered, produced and/or exported at the building site and nearby);
- e) a set of overall formulae and input-output relations, linking the various elements relevant for the assessment of the overall EPB;
- f) general requirements for EPB dealing with partial calculations;
- g) rules for the combination of different spaces into zones;
- h) performance indicators;
- i) methodology for measured energy performance assessment.

ISO 10077 consists of two parts. This document is intended to provide calculated values of the thermal characteristics of frame profiles, suitable for use as input data in the calculation method of the thermal transmittance of windows, doors and shutters given in ISO 10077-1. It is an alternative to the hot box test method specified in EN 12412-2. In some cases, the hot box method can be preferred, especially if physical and geometrical data are not available or if the profile is of complicated geometrical shape.

Although the method in this document basically applies to vertical frame profiles, it is an acceptable approximation for horizontal frame profiles (e.g. sill and head sections) and for products used in sloped positions (e.g. roof windows). For calculations made with the glazing units in place, the heat flow pattern and the temperature field within the frame are useful by-products of this calculation.

The ISO 10077 series does not cover building facades and curtain walling, which are covered in ISO 12631.

[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.

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									
4	Ways to express energy performance		Ways to express energy performance		Ways to express energy performance									
5	Building categories and building boundaries		Heat transfer by transmission	ISO 10077-2	Emission and control									
6	Building occupancy 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 zoning		Solar heat gains		Generation and control									
9	Calculated energy performance		Building dynamics (thermal mass)		Load dispatching and operating conditions									

^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
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 The shaded modules are not applicable.														

Thermal performance of windows, doors and shutters — Calculation of thermal transmittance —

Part 2: Numerical method for frames

1 Scope

This document specifies a method and gives reference input data for the calculation of the thermal transmittance of frame profiles and of the linear thermal transmittance of their junction with glazing or opaque panels.

The method can also be used to evaluate the thermal resistance of shutter profiles and the thermal characteristics of roller shutter boxes and similar components (e.g. blinds).

This document also gives criteria for the validation of numerical methods used for the calculation.

This document does not include effects of solar radiation, heat transfer caused by air leakage or three-dimensional heat transfer such as pinpoint metallic connections. Thermal bridge effects between the frame and the building structure are not included.

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 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 10292, *Glass in building — Calculation of steady-state U values (thermal transmittance) of multiple glazing*

ISO 10456:2007, *Building materials and products — Hygrothermal properties — Tabulated design values and procedures for determining declared and design thermal values*

ISO 12567-2:2005, *Thermal performance of windows and doors — Determination of thermal transmittance by hot box method — Part 2: Roof windows and other projecting windows*

ISO 17025, *General requirements for the competence of testing and calibration laboratories*

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

EN 673, *Glass in building — Calculation of thermal transmittance (U-value) — Calculation Method*

EN 12519, *Windows and pedestrian doors — Terminology*

NOTE 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).

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 7345, EN 12519, 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

EPB standard

standard that complies with the requirements given in ISO 52000-1, CEN/TS 16628^[10] and CEN/TS 16629^[11]

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 (Mandate M/480), and support essential requirements of EU Directive 2010/31/EU on the energy performance of buildings (EPBD). Several EPB standards and related documents are developed or revised under the same mandate.

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

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	Name of quantity	Unit
A	area	m ²
b	width, i.e. perpendicular to the direction of heat flow	m
d	depth, i.e. parallel to the direction of heat flow	m
C	constant in formula for Nusselt number	W/(m ² ·K ^{4/3})
E	intersurface emittance	—
F	view factor	—
h	heat transfer coefficient	W/(m ² ·K)
L^{2D}	two-dimensional thermal conductance or thermal coupling coefficient	W/(m·K)
l	length	m
Nu	Nusselt number	—
q	density of heat flow rate	W/m ²
R	thermal resistance	m ² ·K/W
r	distance	m
T	thermodynamic temperature	K
U	thermal transmittance	W/(m ² ·K)
σ	Stefan-Boltzmann constant	W/(m ² ·K ⁴)

Symbol	Name of quantity	Unit
ε	emissivity	—
λ	thermal conductivity	W/(m·K)
Ψ	linear thermal transmittance	W/(m·K)
θ	temperature	°C

4.2 Subscripts

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

Subscript	Description
c	convective (surface to surface)
e	external (outdoor)
g	glazing
eq	equivalent
f	frame
fr	frame adjacent to roller shutter box
i	internal (indoor)
rb	radiation black body
m	mean
p	panel
r	radiative
s	space (air or gas space)
sb	shutter box
se	external surface
si	internal surface

5 Calculation method

5.1 Output of the method

The possible outputs of this document are the following:

- thermal transmittance of a frame profile, U_f ;
- thermal transmittance of a shutter box, U_{sb} ;
- linear thermal transmittance of a junction of a frame profile with a glazing, Ψ_g or opaque panel, Ψ_p .

5.2 General principle

The calculation is carried out using a two-dimensional numerical method conforming to ISO 10211. The elements shall be divided such that any further division does not change the calculated result significantly. ISO 10211 gives criteria for judging whether sufficient sub-divisions have been used.

Two different approaches for the calculation of the heat transfer through cavities are given:

- a) radiosity method;
- b) single equivalent thermal conductivity method.

The radiosity method considers that the heat transfer through an air cavity occurs simultaneously through conduction/convection and through radiation. The two phenomena are happening in parallel so that the calculation of each contribution is done separately.

When using the single equivalent thermal conductivity method the heat flow rate in cavities is represented by a single equivalent thermal conductivity, λ_{eq} . This equivalent thermal conductivity includes the heat flow by conduction, by convection and by radiation, and depends on the geometry of the cavity and on the adjacent materials.

NOTE The single equivalent thermal conductivity method is equal to the calculation method given in ISO 10077-2:2012.

Vertical orientation of frame sections and air cavities is assumed for calculations by this document for the purposes of assigning equivalent thermal conductivity values (see [6.4.2.3.2](#) and [6.4.3.4.2](#)). This applies irrespective of the intended orientation of the actual window, including roof windows.

Throughout this document, where indicated in the text, [Table C.1](#) shall be used to identify alternative regional references in line with ISO Global Relevance Policy.

5.3 Validation of the calculation programs

To ensure the suitability of the calculation program used, calculations shall be carried out on the examples described in [Annexes G](#) and [H](#) (using the radiosity method) or [Annex I](#) (using the single equivalent thermal conductivity).

The requirements for all validation cases in [Annexes G](#) and [H](#) or [Annex I](#) shall be fulfilled.

The calculated two-dimensional thermal conductance L^{2D} for the cases in [Annex H](#) or [Annex I](#) shall not differ from the corresponding values given in [Tables H.3](#) and [H.4](#) or [Tables I.3](#) and [I.4](#) by more than $\pm 3\%$. This will lead to an accuracy of the thermal transmittance, U , and the linear thermal transmittance, Ψ , of about 5 %.

6 Calculation of thermal transmittance

6.1 Output data

The outputs of this document are transmission heat transfer coefficients as shown in [Table 2](#).

Table 2 — Output data

Description	Symbol	Unit	Destination module	Validity interval	Varying
Thermal transmittance of frame profile	U_f	W/(m ² K)	M2-5	>0... 20	No
Thermal transmittance of shutter box	U_{sb}	W/(m ² K)	M2-5	>0... 20	No
Linear thermal transmittance	Ψ	W/(m K)	M2-5	-20... 20	No

6.2 Calculation time intervals

The calculations described in this document are steady-state and do not have time intervals.

6.3 Input data

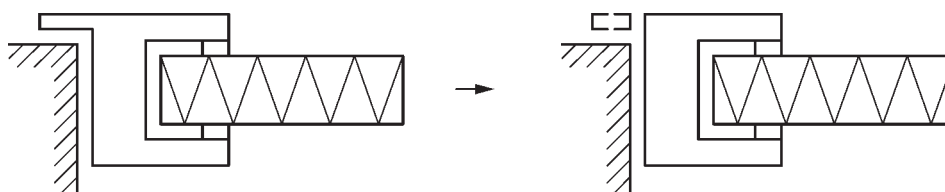
6.3.1 Geometrical characteristics

[Table 3](#) shows the necessary geometrical characteristics.

Table 3 — Identifiers for geometric characteristics

Description	Symbol	Unit	Range	Origin	Varying
Geometrical data					
Cross section of the frame profile				Manufacturer	No
Cross section of the shutter box				Manufacturer	No
Cross section of the junction frame profile and glazing				Manufacturer	No
Cross section of the junction frame profile and panel				Manufacturer	No

For frames with special extensions overlapping the wall or other building elements, such as Z-shaped profiles, the extensions shall be disregarded as illustrated in [Figure 1](#). This applies to all profiles with special extensions (e.g. H-shape) where the extensions overlap the wall or other building elements. Other boundaries shall be treated as defined in [Figure 4](#).

**Figure 1 — Treatment of profiles with extensions (Z-shape)**

NOTE 1 This approximation is for assessment of thermal transmittance. It is not appropriate for the assessment of condensation risk.

NOTE 2 The extension of the frame profile is disregarded in the calculation of the thermal transmittance of the window; see ISO 10077-1.

6.3.2 Thermal conductivity values

For the purpose of this document, thermal conductivity values used for solid materials shall be obtained according to one of the following:

- [Table D.1](#);
- tabulated values given in ISO 10456;
- product standards;
- technical approvals by a recognized national body;
- measurements according to an appropriate International Standard.

Measurements shall be used only if there is no tabulated data or data according to relevant product standards or a technical approval. Measurements shall be performed at a mean temperature of 10 °C using the appropriate method by an institute accredited (as specified in ISO 17025) to carry out those measurements, on samples that have been conditioned at 23 °C and 50 % RH to constant mass (change in mass not more than 0,1 % over 24 h). To ensure that the thermal conductivity values are representative of the material (that is, that the value incorporates likely variability of the material and the measurement uncertainty), one of the following methods shall be used for obtaining the thermal conductivity value from measured data used in the calculations:

- the thermal conductivity is the declared value obtained from the measured data (at least three different samples from different lots representing the usual product variation, with ageing taken

into consideration) according to a statistical evaluation as defined in ISO 10456:2007, Annex C, 90 % fractile;

- if less than three samples, use the mean value multiplied by a factor of 1,25.

6.3.3 Emissivity of surfaces

The surfaces bounding an air cavity shall have an emissivity of 0,9. Values less than 0,9 may be used only if taken from [Table D.3](#) or measured in accordance with an appropriate standard by an institute accredited (as specified in ISO 17025) to carry out those measurements. Where based on measured values, there shall be at least three samples and the results shall be evaluated according to the statistical treatment in ISO 10456.

NOTE Metallic surfaces such as aluminium alloy frame, steel reinforcement and other metals/alloys have lower emissivity. Typical values of the emissivity for metallic surfaces are given in [Table D.3](#).

6.3.4 General boundaries

The external and internal surface resistances depend on the convective and radiative heat transfer to the external and internal environments. If an external surface is not exposed to normal wind conditions, the convective part may be reduced in edges or junctions between two surfaces. The surface resistances for horizontal heat flow are given in [Annex E](#). These values shall be used for calculations by this document irrespective of the intended orientation of the actual window, including roof windows. Surface condensation shall be assessed on the basis of the lowest internal surface temperature calculated using the surface resistances in [Annex E](#).

The cutting plane of the infill and the cutting plane to neighbouring material shall be taken as adiabatic (see [Figure 4](#) and [Annex H](#)).

The reference temperature conditions shall be 20 °C internal and 0 °C external.

6.3.5 Boundaries for roller shutter boxes

Calculation of the thermal transmittance of a roller shutter box shall be done with the following boundary conditions:

- the top of the roller shutter box: adiabatic;
- at the bottom of the roller shutter box where it adjoins the window frame: adiabatic for a distance of 60 mm;
- surfaces adjacent to the internal environment: surface resistance of 0,13 m²·K/W;
- surfaces adjacent to the external environment: surface resistance of 0,04 m²·K/W.

The cavity within the roller shutter box shall be treated as (see [Figure 2](#)):

- if $e_1 + e_3 \leq 2$ mm: unventilated; the equivalent thermal conductivity of an unventilated air cavity is calculated according to [6.4.2.3](#);

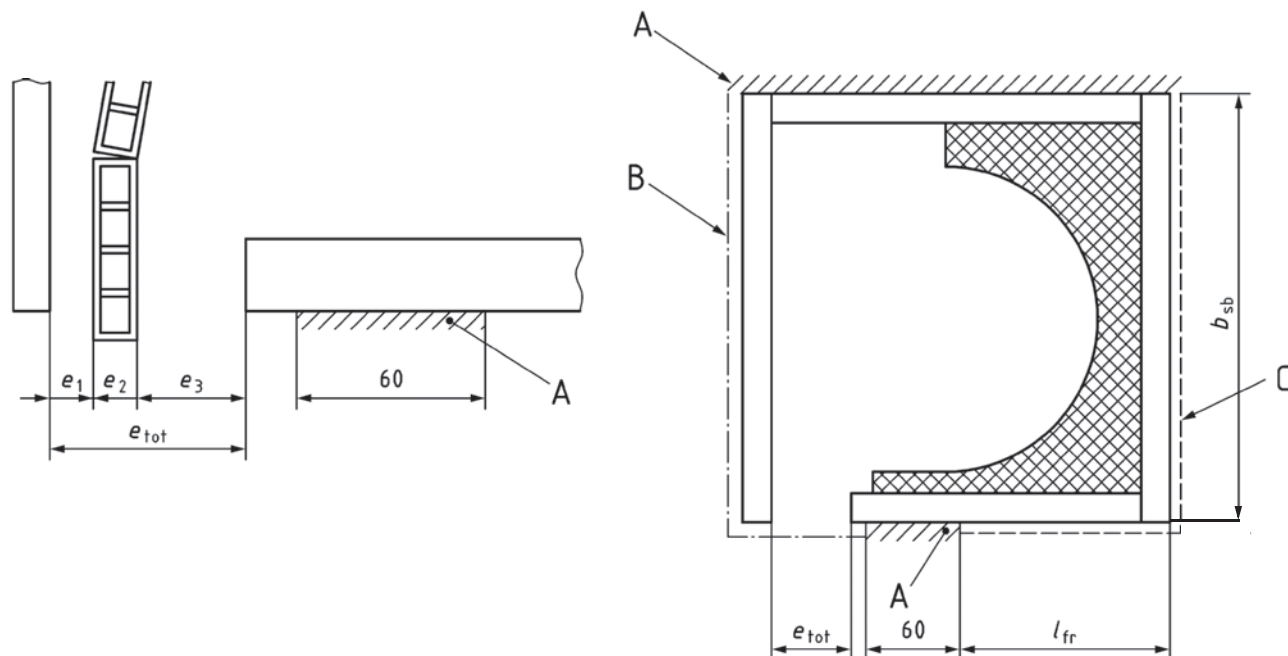
NOTE Additional hardware like brushes, gaskets, etc. can be taken into account for the determination of e_1 and e_3 .

- if $e_{\text{tot}} \leq 35$ mm: slightly ventilated; taking the air temperature within the cavity equal to the external air temperature but with a surface resistance of 0,30 m²·K/W;
- if $e_{\text{tot}} > 35$ mm: well-ventilated; taking the air temperature within the cavity equal to the external air temperature but with a surface resistance of 0,13 m²·K/W.

The relevant height of the roller shutter box, b_{sb} , used for the calculation is the projected distance between the upper and lower adiabatic boundary (see [Figure 2](#)).

The assessment may be done with insulation on either or both of the boundaries B and C indicated in [Figure 2](#). If that is the case the thickness and thermal conductivity of the insulation shall be stated in the calculation report.

Dimensions in millimetres



Key

Boundaries (see [Annex E](#)):

A	adiabatic boundary	b_{sb}	height of the roller shutter box
B	external surface resistance	e_1, e_3	widths of air gaps on either side of the shutter where it exits from the shutter box
C	internal surface resistance	e_2	thickness of the shutter
		e_{tot}	$e_1 + e_2 + e_3$
		l_{fr}	position of the frame

NOTE The window frame (boundary A) is 60 mm wide but located with respect to the roller shutter box according to the actual situation.

Figure 2 — Schematic example for the treatment of the boundaries for roller shutter boxes

6.4 Calculation procedures

6.4.1 Determination of thermal transmittance

The thermal transmittance of a frame section shall be determined with the glazing replaced by an insulating panel according to [Annex E](#), with the external and internal surface resistances taken from [Annex E](#). The linear thermal transmittance of the interaction of frame and glazing shall be determined from calculations with the glazing in place and with the glazing replaced by an insulated panel.

NOTE 1 The interaction of the frame and the building structure is considered separately for the building as a whole. It is not part of the thermal transmittance of the frame section.

NOTE 2 In the case of an overlap between the frame section and part of the wall, the linear thermal transmittance could be negative.

6.4.2 Treatment of cavities using the radiosity method

6.4.2.1 General

The heat transfer through an air cavity occurs simultaneously through convection and through radiation. The two phenomena are happening in parallel so that the calculation of each contribution can be done separately.

The calculation of the convective heat transfer is carried out using an equivalent thermal conductivity and following the rules of [6.4.2.3.2](#). Given that the formula for the equivalent thermal conductivity applies to rectangular cavities with the convective heat flow parallel to the depth of the cavity only, non-rectangular cavities or rectangular cavities with the convective heat flow not parallel to the depth of the cavity must be first transformed into equivalent rectangular cavities, correctly oriented with regards to the direction of the convective heat flow.

The calculation of the radiative heat transfer is carried out for the real geometry of the cavities (but after applying the subdivision rule for interconnected cavities, see [6.4.2.3.1](#)) using a view factor-based radiosity method, as explained in [6.4.2.3.3](#).

Both convective and radiative heat transfer calculations depend on the temperature itself (nonlinear calculations). Therefore, an iterative calculation procedure of the heat flow shall be adopted.

[Figure 3](#) shows the flowchart of the general methodology.

NOTE 1 In contrast to other standards and to [6.4.3](#), the equivalent thermal conductivity here includes only the effect of the convective heat transfer (radiative heat transfer is taken into account separately).

NOTE 2 The terms “convective heat transfer” and “convective heat flow” are used to represent heat transfer by both conduction and convection.

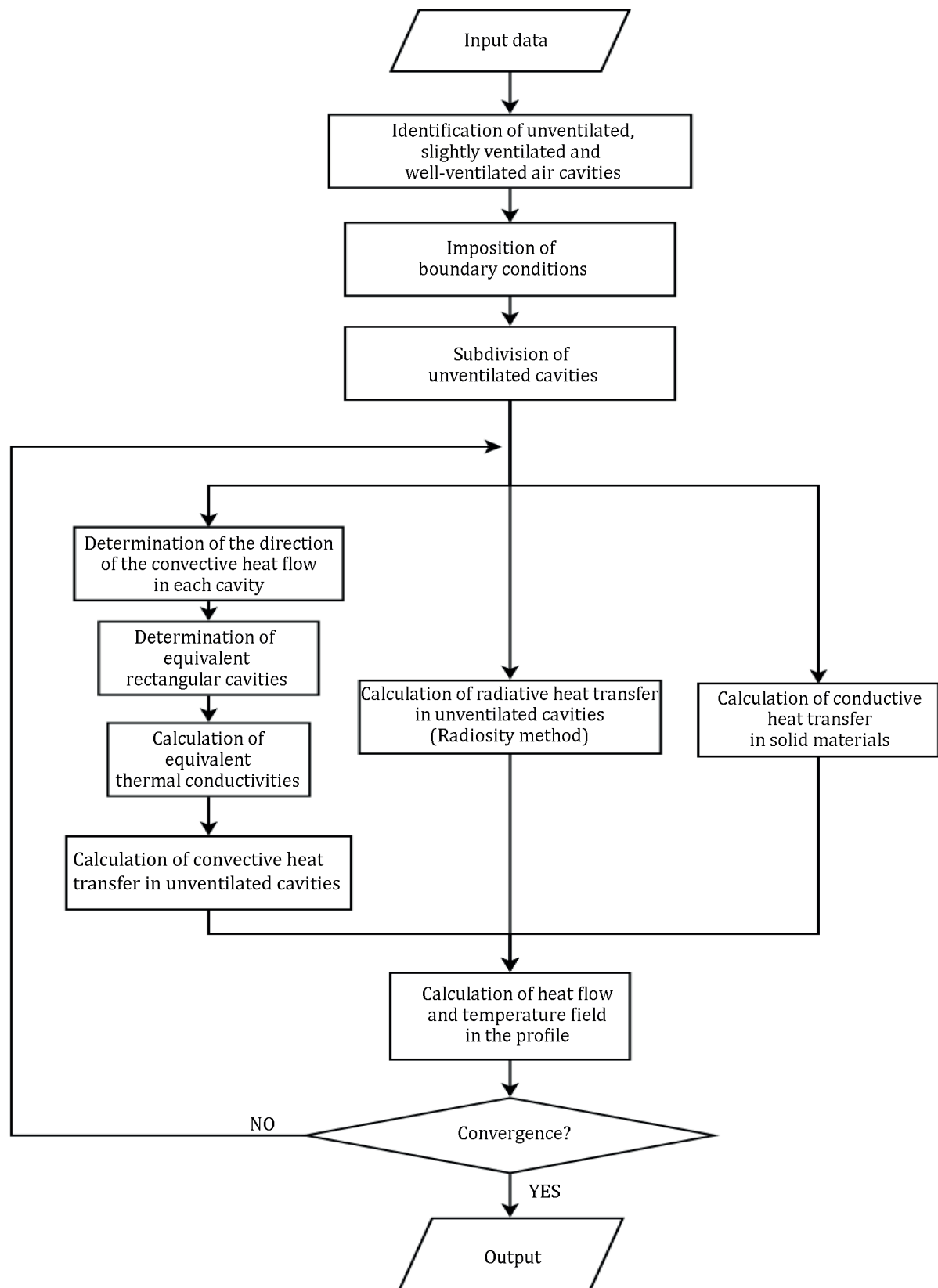


Figure 3 — Flowchart of the calculation method

6.4.2.2 Cavities in glazing

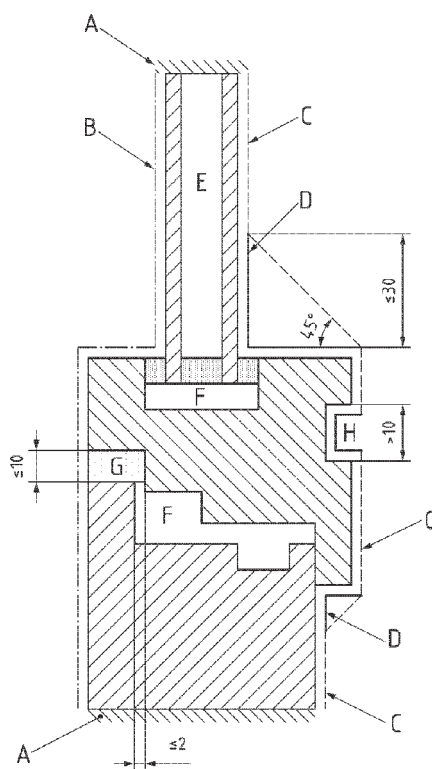
The equivalent thermal conductivity of an unventilated space between glass panes in glazing shall be determined according to ISO 10292 (or see Subject 1 in [Table C.1](#)). The resulting equivalent conductivity shall be used in the whole cavity, up to the edge.

6.4.2.3 Unventilated air cavities in frames and roller shutter boxes

6.4.2.3.1 Definition

Air cavities are unventilated if they are completely closed or connected either to the exterior or to the interior by a slit with a width not exceeding 2 mm (see [Figures 4](#) and [5](#)); this applies irrespective of the orientation of the cavity with respect to heat flow direction. Otherwise the cavity shall be treated as ventilated or slightly ventilated (see [6.4.2.4](#)).

Dimensions in millimetres



Key

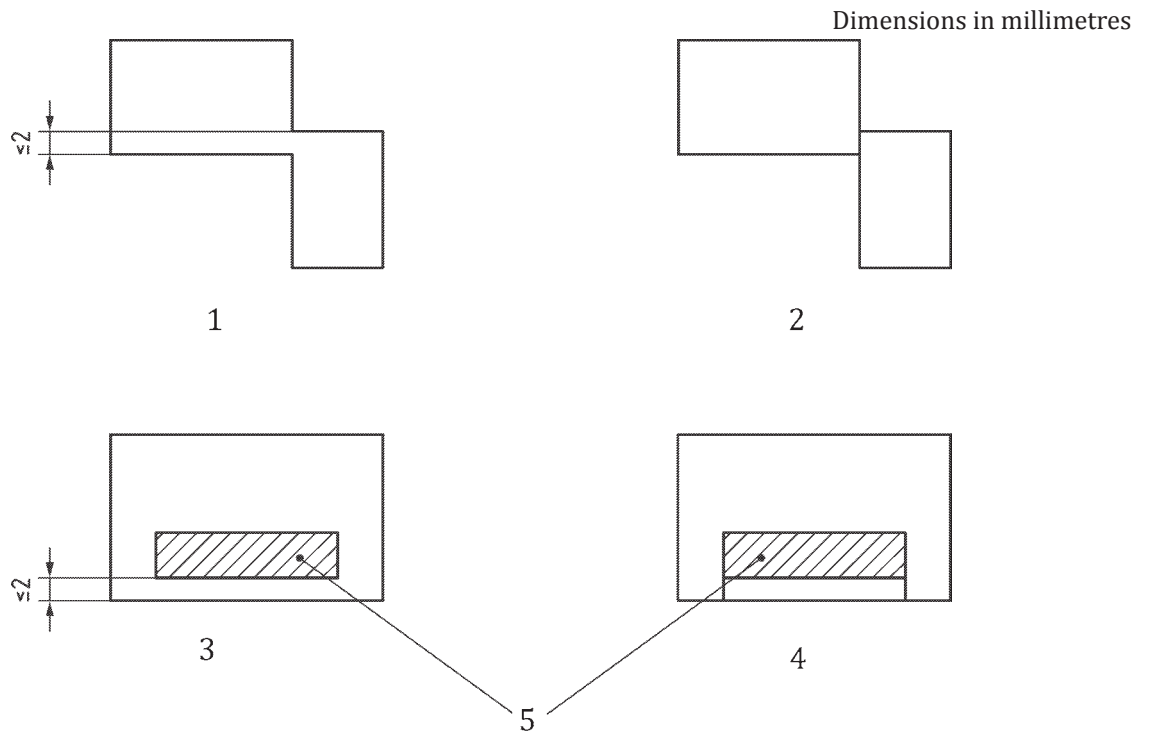
Boundaries (see [Annex E](#)):

A	adiabatic boundary	E	glazing (see 6.4.2.2)
B	external surface resistance	F	unventilated cavity (see 6.4.2.3)
C	internal surface resistance	G	slightly ventilated cavity or groove (see 6.4.2.4.1)
D	increased surface resistance	H	well-ventilated cavity or groove (see 6.4.2.4.2)

Figure 4 — Schematic example for the treatment of boundaries and cavities and grooves of a frame section

NOTE [Figure 4](#) illustrates a window. The same principles are applicable to roof windows, but the adiabatic part of the boundary is different: An example of a roof window is shown in [Figure H.6](#).

Cavities with one dimension not exceeding 2,0 mm or cavities with an interconnection not exceeding 2,0 mm shall be considered as separate, see [Figure 5](#).

**Key**

- 1 cavities connected by a section less than or equal to 2 mm
- 2 cavities in 1 treated as separated cavities
- 3 small cavity with a width less than or equal to 2,0 mm
- 4 cavity in 3 treated as separated cavities
- 5 solid material

Figure 5 — Division of cavity**6.4.2.3.2 Convective heat transfer in unventilated air cavities**

In order to calculate the convective heat transfer in a cavity, an equivalent thermal conductivity is used. Its value is given by [Formula \(1\)](#):

$$\lambda_{eq} = \lambda_{air} \cdot Nu \quad (1)$$

where

λ_{air} is the thermal conductivity of air = 0,025 W/(m·K);

Nu is the Nusselt number.

The Nusselt number is calculated as follows:

if $b < 5$ mm: $Nu = 1$

otherwise

$$Nu = \max \left[1, \frac{dC\Delta T^{1/3}}{\lambda_{\text{air}}} \right] \quad (2)$$

where

b is the width of the equivalent rectangular cavity perpendicular to the direction of heat flow, in m (see also Figure 6);

d is the depth of the equivalent rectangular cavity in the direction of heat flow, in m (see also Figure 6);

C is a constant equal to $0,73 \text{ W}/(\text{m}^2 \cdot \text{K}^{4/3})$;

ΔT is the maximum surface temperature difference in the real cavity, in K.

As ΔT is initially unknown, the calculation of the convective heat transfer is iterative. A temperature difference of 10 K can be considered for the first iteration.

In order to calculate the convective heat transfer in non-rectangular cavities or in rectangular cavities with the convective heat flow not parallel to the depth of the cavity, these cavities are first transformed into equivalent rectangular cavities.

Air cavities are transformed into equivalent rectangular air cavities with the same area ($A = A'$) and aspect ratio ($d/b = d'/b'$), see Figure 6.

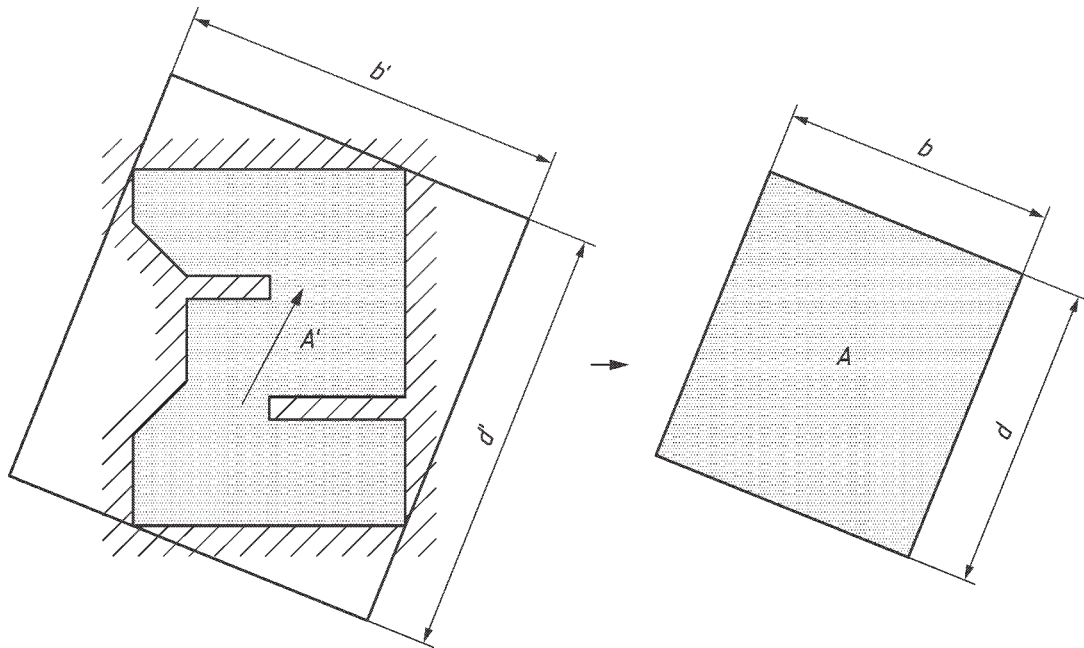
The transformation is given by Formulae (3) and (4):

$$b = \sqrt{A' \frac{b'}{d'}} \quad (3)$$

$$d = \sqrt{A' \frac{d'}{b'}} \quad (4)$$

The calculation of the dimensions of the equivalent rectangular cavity requires the determination of the convective heat flow direction.

The convective heat flow direction in the cavity is a direction in the cross-sectional plane of the frame section corresponding to the main direction of the convective heat flow in the cavity.

**Key**

A area of the equivalent rectangular air cavity

d, b depth and width of the equivalent air cavity

A' area of the true cavity

d', b' depth and width of the circumscribing rectangle with d' parallel to the convective heat flow direction

Figure 6 — Transformation of air cavities

From a known temperature distribution in the cavity as shown in [Figure 7](#) the convective heat flow direction equals the direction of the vector $\bar{q}_m$ calculated as [Formula \(5\)](#):

$$\bar{q}_m = \frac{\int_A \bar{q} dA}{A} = \frac{\int_A -\lambda_{eq} \text{grad}T dA}{A} \quad (5)$$

where

$\bar{q}_m$ is the mean heat flow density, in W/m²;

$\bar{q}$ is the local heat flow density, in W/m²;

A is the cross-sectional area of the cavity, in m²;

λ_{eq} is the equivalent thermal conductivity of the cavity, in W/(m·K);

$\text{grad}T$ is the temperature gradient of the gas within the cavity, in K/m.

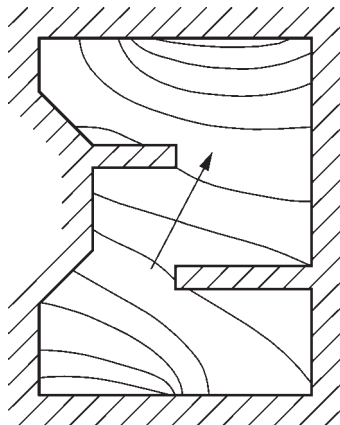


Figure 7 — Cavity conductive heat flow direction

As the temperature field, and therefore, the direction of the convective heat flow are initially unknown, the calculation of the convective heat transfer is iterative.

6.4.2.3.3 Radiative heat exchange

The radiative heat exchange between the elementary surfaces around the air cavity (resulting from the grid used by the numerical method) shall be calculated using the radiosity method. The radiosity method assumes isothermal elementary surfaces to be characterized by a uniform radiosity and irradiance. The surfaces are assumed to have opaque, diffuse and grey surface behaviour. The air within the cavity is taken to be non-participating (i.e. the gas does not absorb radiation).

NOTE 1 Definitions of the terms radiosity, irradiance, opaque, diffuse and grey are given in ISO 9288.

The radiative heat exchange according to the radiosity method can be represented by a thermal resistance network as shown, for example, in Figure 8.

NOTE 2 Only four elementary surfaces occur in the network shown. In real cavities, multiple elementary surfaces will occur.

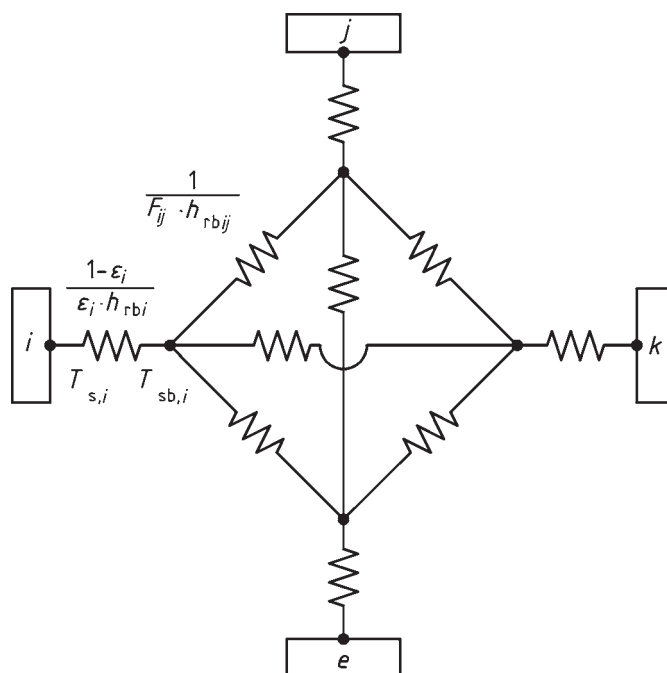


Figure 8 — Example of radiation thermal resistance network

The network is specified as follows:

- in the surface node i , the temperature T_{si} is applied;
- the node adjacent to the surface node i (so-called black surface node i) has temperature T_{sbi} ;
- the radiative heat flow between two black surface nodes i and j is defined in [Formulae \(6\), \(7\)](#) and [\(8\)](#):

$$Q_{ij} = \frac{A_i (T_{sbi} - T_{sbj})}{R_{ij}} \quad (6)$$

$$R_{ij} = \frac{1}{F_{ij} h_{rb,ij}} \quad (7)$$

$$h_{rb,ij} = \sigma (T_{sbi}^2 + T_{sbj}^2) (T_{sbi} + T_{sbj}) \quad (8)$$

where

A_i is area of elementary surface i , in m^2 ;

F_{ij} is the view factor from surface i to surface j ;

$h_{rb,ij}$ is the black radiation heat transfer coefficient between surface node i and surface node j , in $W/(m^2 \cdot K)$;

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

T_{sbi} is absolute temperature of black surface node i , in K;

T_{sbj} is absolute temperature of black surface node j , in K;

- The radiative heat flow between a black surface node i and a surface node i is defined in [Formulae \(9\), \(10\)](#) and [\(11\)](#):

$$Q_i = \frac{A_i (T_{sbi} - T_{si})}{R_i} \quad (9)$$

$$R_i = \frac{1 - \varepsilon_i}{\varepsilon_i h_{rbi}} \quad (10)$$

$$h_{rbi} = \sigma (T_{sbi}^2 + T_{si}^2) (T_{sbi} + T_{si}) \quad (11)$$

where

A_i is the area of the elementary surface i , in m^2 ;

ε_i is the total hemispherical emissivity of surface i ;

h_{rbi} is the black radiation heat transfer coefficient between surface node i and black surface node i , in $W/(m^2 \cdot K)$;