INTERNATIONAL STANDARD

ISO 10211-1

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Thermal bridges in building construction — Heat flows and surface temperatures —

Part 1:
General calculation methods

Ponts thermiques dans le bâtiment — Flux de chaleur et températures superficielles —

Partie 1: Méthodes générales de calcul

Reference number
ISO 10211-1:1995(E)

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.

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

International Standard ISO 10211-1 was prepared by the European Committee for Standardization (CEN) in collaboration with Technical Committee ISO/TC 163, *Thermal insulation*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

ISO 10211 consists of the following part, under the general title *Thermal bridges in building construction — Heat flows and surface temperatures*:

— *Part 1: General calculation methods*

The following part is in preparation:

— *Part 2: Calculation of linear thermal bridges*

Annexes A, B and C form an integral part of this part of ISO 10211. Annexes D, E, F and G are for information only.

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Foreword

The text of EN ISO 10211-1:1995 has been prepared by Technical Committee CEN/TC 89 "Thermal performance of buildings and building components" in collaboration with ISO/TC 163 "Thermal insulation".

This European Standard shall be given the status of a National Standard, either by publication of an identical text or by endorsement, at the latest by February 1996, and conflicting national standards shall be withdrawn at the latest by February 1996.

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

Introduction

Thermal bridges, which in general occur at any junction between building components or where the building structure changes composition, have two consequences:

a) a change in heat flow rate

and

b) a change in internal surface temperature

compared with those of the unbridged structure.

Although similar calculation procedures are used, the procedures are not identical for the calculation of heat flows and of surface temperatures.

Usually a thermal bridge gives rise to 3-dimensional or 2-dimensional heat flows, which can be precisely determined using detailed numerical calculation methods as described in this standard. These are termed "Class A" methods, and Part 1 of this standard lays down criteria which have to be satisfied in order that a method can be described as being "Class A".

In many applications numerical calculations which are based on a 2-dimensional representation of the heat flows provide results with an adequate accuracy. These are termed "Class B" methods.
Part 2 of this standard lays down criteria for the calculation of linear thermal bridges which have to be satisfied in order that the calculation method can be described as being "Class B".

Other less precise but much simpler methods, which are not based on numerical calculation may provide adequate assessment of the additional heat loss caused by thermal bridges. Simplified methods are given in prEN ISO 14683, Thermal bridges in building constructions - Linear thermal transmittance - Simplified methods and design values (ISO/DIS 14683:1995).

1 Scope

Part 1 of this standard sets out the specifications on a 3-D and 2-D geometrical model of a thermal bridge for the numerical calculation of:

- heat flows in order to assess the overall heat loss from a building;

- minimum surface temperatures in order to assess the risk of surface condensation.

These specifications include the geometrical boundaries and subdivisions of the model, the thermal boundary conditions and the thermal values and relationships to be used.

The standard is based upon the following assumptions:

- steady-state conditions apply;
- all physical properties are independent of temperature;
- there are no heat sources within the building element.

It may also be used for the derivation of linear and point thermal transmittances and of surface temperature factors.

2 Normative references

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

ISO 7345	Thermal insulation - Physical quantities and definitions
prEN 673	Thermal insulation of glazing - Calculation rules for determining the steady state thermal transmittance of glazing
prEN ISO 6946-1	Building components and building elements - Thermal resistance and thermal transmittance - Calculation method
prEN ISO 10456	Thermal insulation - Building materials and products - Determination of declared and design values
prEN ISO 13789	Thermal performance of buildings - Specific transmission heat loss - Calculation method

3 Definitions and symbols

3.1 Definitions

For the purposes of this standard, the definitions of ISO 7345 and the following definitions apply:

3.1.1 thermal bridge: Part of the building envelope where the otherwise uniform thermal resistance is significantly changed by:

a) full or partial penetration of the building envelope by materials with a different thermal conductivity

and/or

b) a change in thickness of the fabric

and/or

c) a difference between internal and external areas, such as occur at wall/floor/ceiling junctions.

3.1.2 3-D geometrical model: Geometrical model, deduced from building plans, such that for each of the orthogonal axes, the cross section perpendicular to that axis changes within the boundary of the model (see figure 1).

3.1.3 3-D flanking element: Part of the 3-D geometrical model which, when considered in isolation, can be represented by a 2-D geometrical model (see figure 1 and 2).

3.1.4 3-D central element: Part of the 3-D geometrical model which is not a 3-D flanking element (see figure 1).

3.1.5 2-D geometrical model: Geometrical model deduced from building plans, such that for one of the orthogonal axes, the cross-section perpendicular to that axis does not change within the boundaries of the model (see figure 2).

NOTE: A 2-D geometrical model is used for two-dimensional calculations.

3.1.6 construction planes: Planes in the 3-D or 2-D model which separate:
- different materials;
- the geometrical model from the remainder of the construction;
- the flanking elements from the central element.

(see figure 3).

3.1.7 cut-off planes: Those construction planes that are boundaries to the 3-D model or 2-D model by separating the model from the remainder of the construction (see figure 3).

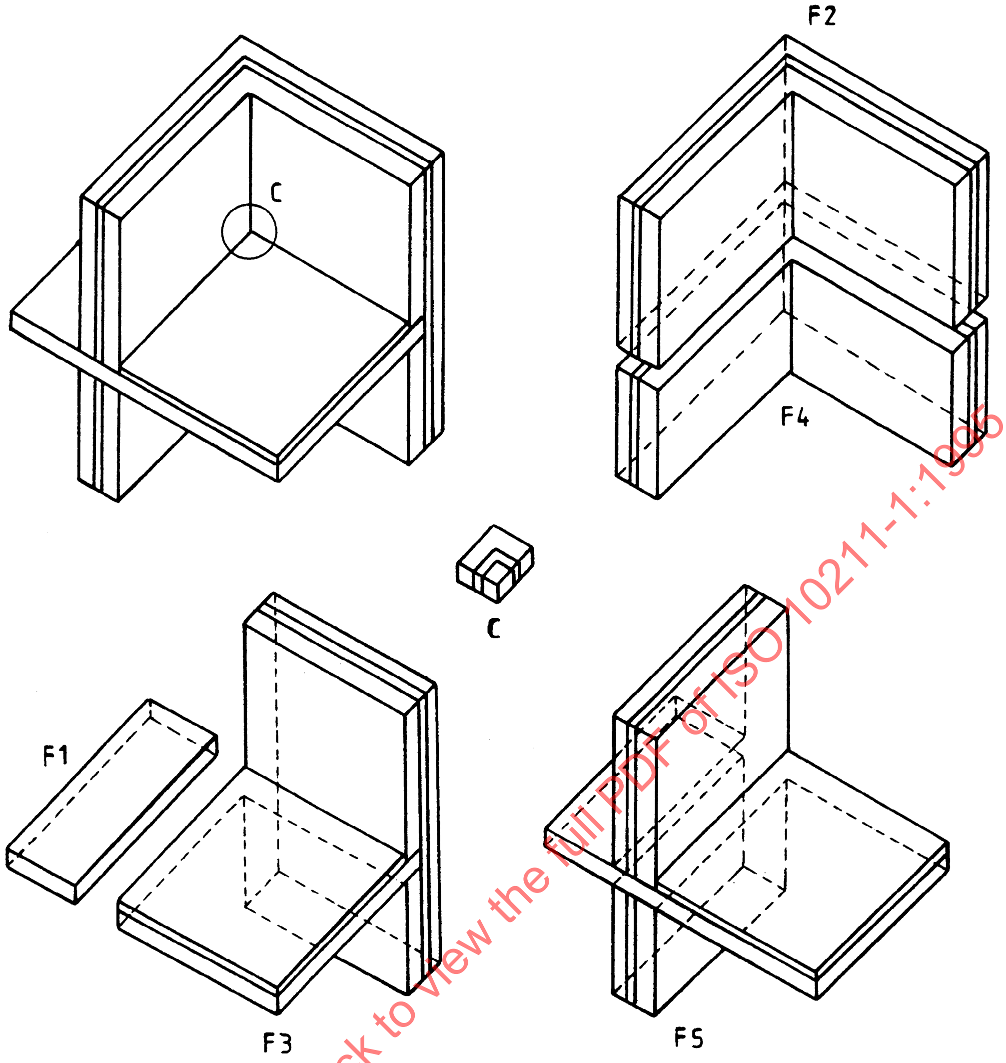


Figure 1: 3-D model with five 3-D flanking elements and one 3-D central element. F1 to F5 have constant cross-sections perpendicular to at least one axis. C is the remaining part

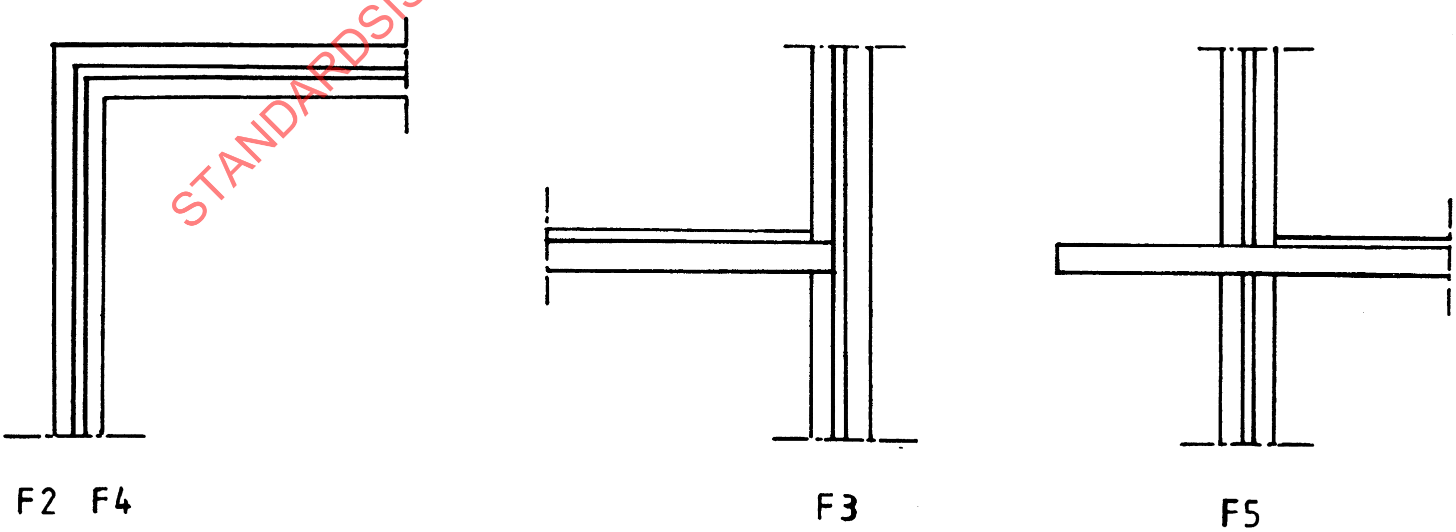


Figure 2: The cross sections of the flanking elements in a 3-D model can be treated as 2-D models. F2 to F5 refer to figure 1.

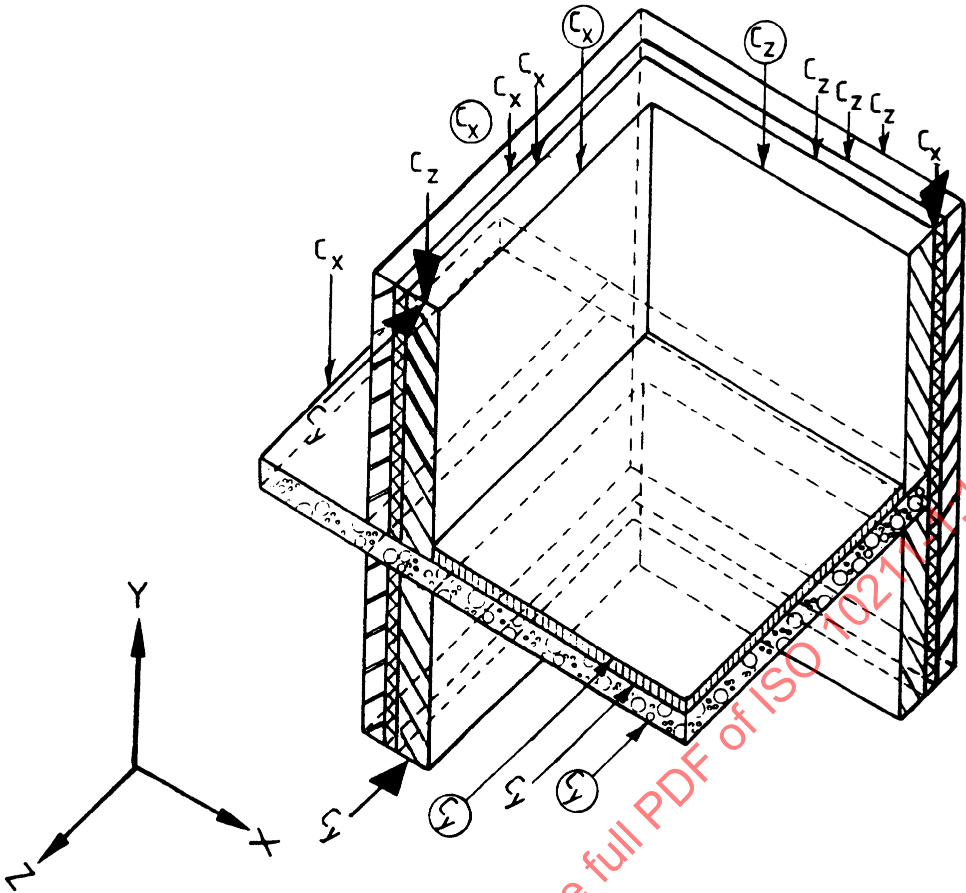


Figure 3: Example of a 3-D model showing construction planes.
C_x are construction planes perpendicular to the x-axis
C_y are construction planes perpendicular to the y-axis
C_z are construction planes perpendicular to the z-axis
Cut-off planes are indicated with enlarged arrows. Planes that separate flanking elements from the central element are encircled.

3.1.8 auxiliary planes: Planes which, in addition to the construction planes, divide the geometrical model into a number of cells.

3.1.9 quasi-homogeneous layer: Layer which consists of two or more materials with different thermal conductivities, but which can be considered as a homogeneous layer with an effective thermal conductivity (see figure 4).

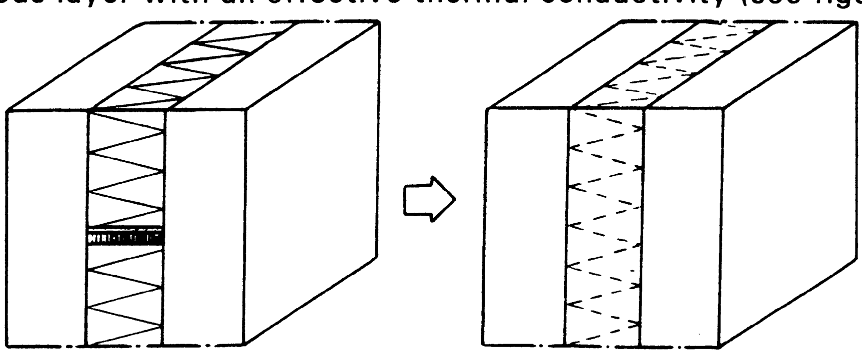


Figure 4: Example of a minor point thermal bridge giving rise to 3-dimensional heat flow, which is incorporated into a quasi-homogeneous layer

3.1.10 temperature difference ratio, ζ_{Rsi}: Difference between the internal air temperature and the temperature of the internal surface, divided by the difference between the internal air temperature and the external air temperature, calculated with a surface resistance R_{si} at the internal surface.

3.1.11 temperature factor at the internal surface, f_{Rsi}: Difference between the temperature of the internal surface and the external air temperature, divided by the difference between the internal air temperature and the external air temperature, calculated with a surface resistance R_{si} at the internal surface.

NOTE: $f_{Rsi} = 1 - \zeta_{Rsi}$

3.1.12 temperature weighting factor, g: Factor which states the relative influence of the air temperatures of the thermal environments upon the surface temperature at the point under consideration.

3.1.13 external reference temperature: External air temperature, assuming that the sky is completely overcast.

3.1.14 internal reference temperature:

(a) Dry resultant temperature in the room under consideration.

(b) Mean value of the internal air temperature in the room under consideration.

NOTE 1: (a) is used when calculating heat flows in order to assess the overall heat loss and (b) is used when calculating surface temperatures in order to assess the risk of surface condensation.

NOTE 2: For calculation purposes the reference temperature is considered to be uniform throughout the internal environment.

3.1.15 dry resultant temperature: The arithmetic mean value of the internal air temperature and the mean radiant temperature of all surfaces surrounding the internal environment.

3.1.16 thermal coupling coefficient, $L_{i,j}$: Heat flow per unit temperature difference between two environments i,j which are thermally connected by the construction under consideration.

3.1.17 linear thermal transmittance, Ψ: Correction term for the linear influence of a thermal bridge when calculating the thermal coupling coefficient L from 1-D calculations.

3.1.18 point thermal transmittance, χ: Correction term for the point influence of a thermal bridge when calculating the thermal coupling coefficient L from 1-D calculations.

3.2 Symbols and units

Symbol	Physical quantity	Unit
A	area	m^2
H	height	m
L	thermal coupling coefficient	W/K
R	thermal resistance	$m^2 \cdot K/W$
R_{se}	external surface resistance	$m^2 \cdot K/W$
R_{si}	internal surface resistance	$m^2 \cdot K/W$
T	thermodynamic temperature	K
U	thermal transmittance	$W/(m^2 \cdot K)$
V	volume	m^3
b	width	m
d	thickness	m
f_{Rsi}	temperature factor at the internal surface	-
g	temperature weighting factor	-
h	heat transfer coefficient	$W/(m^2 \cdot K)$
l	length	m
q	density of heat flow rate	W/m^2
θ	Celsius temperature	°C
$\Delta\theta$	temperature difference	K
λ	thermal conductivity	$W/(m \cdot K)$
ζ_{Rsi}	temperature difference ratio	-
Φ	heat flow rate	W
χ	point thermal transmittance	W/K
Ψ	linear thermal transmittance	$W/(m \cdot K)$

List of subscripts

cav	cavity
dp	dewpoint
e	exterior
i	interior
l	Linear
min	minimum
s	surface

4 Principles

The *temperature* distribution in and the *heat flow* through a construction can be calculated if the boundary conditions and constructional details are known. For this purpose, the geometrical model is divided into a number of adjacent material cells, each with a homogeneous thermal conductivity. The criteria which shall be met when constructing the model are given in clause 5.

In clause 6 instructions are given for the determination of the values of thermal conductivity and boundary conditions.

The temperature distribution is determined either by means of an iterative calculation or by a direct solution technique, after which the temperature distribution within the material cells is determined by interpolation.

The calculation rules and the method of determining the temperature distribution are described in clause 7.

NOTE: Some of the following clauses contain differences between the calculation of surface temperatures and the calculation of heat flows; the differences are given in tables 1, 3 and 4.

5 Modelling of the construction

5.1 *Rules for modelling*

It is not usually feasible to model a complete building using a single geometrical model. In most cases the building may be partitioned into several parts (including the subsoil where appropriate) by using cut-off planes. This partitioning shall be performed in such a way that any differences in calculation result between the partitioned building and the building when treated as a whole is avoided.
This partitioning into several geometrical models is achieved by choosing suitable cut-off planes.

5.1.1 Cut-off planes of the geometrical model

The geometrical model includes the central element(s), the flanking elements and where appropriate the subsoil. The geometrical model is delimited by cut-off planes.

Cut-off planes shall be positioned as follows:

- at a symmetry plane if this is less than 1 m from the central element (see figure 5);

- at least 1 m from the central element if there is no nearer symmetry plane;

- in the subsoil according to table 1.

NOTE: If there is more than one thermal bridge present in the geometrical model, the calculated surface temperature at the central element of the second thermal bridge is only correct if the second thermal bridge is at a distance of at least 1 m from the nearest cut-off plane (see figure 6), unless the cut-off plane is a symmetry plane.

Dimensions in mm

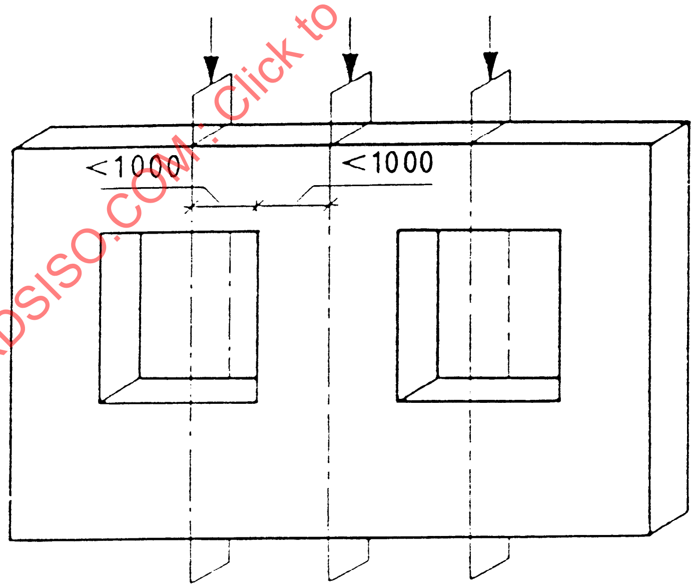


Figure 5: Symmetry planes which can be used as cut-off planes

Dimensions in mm

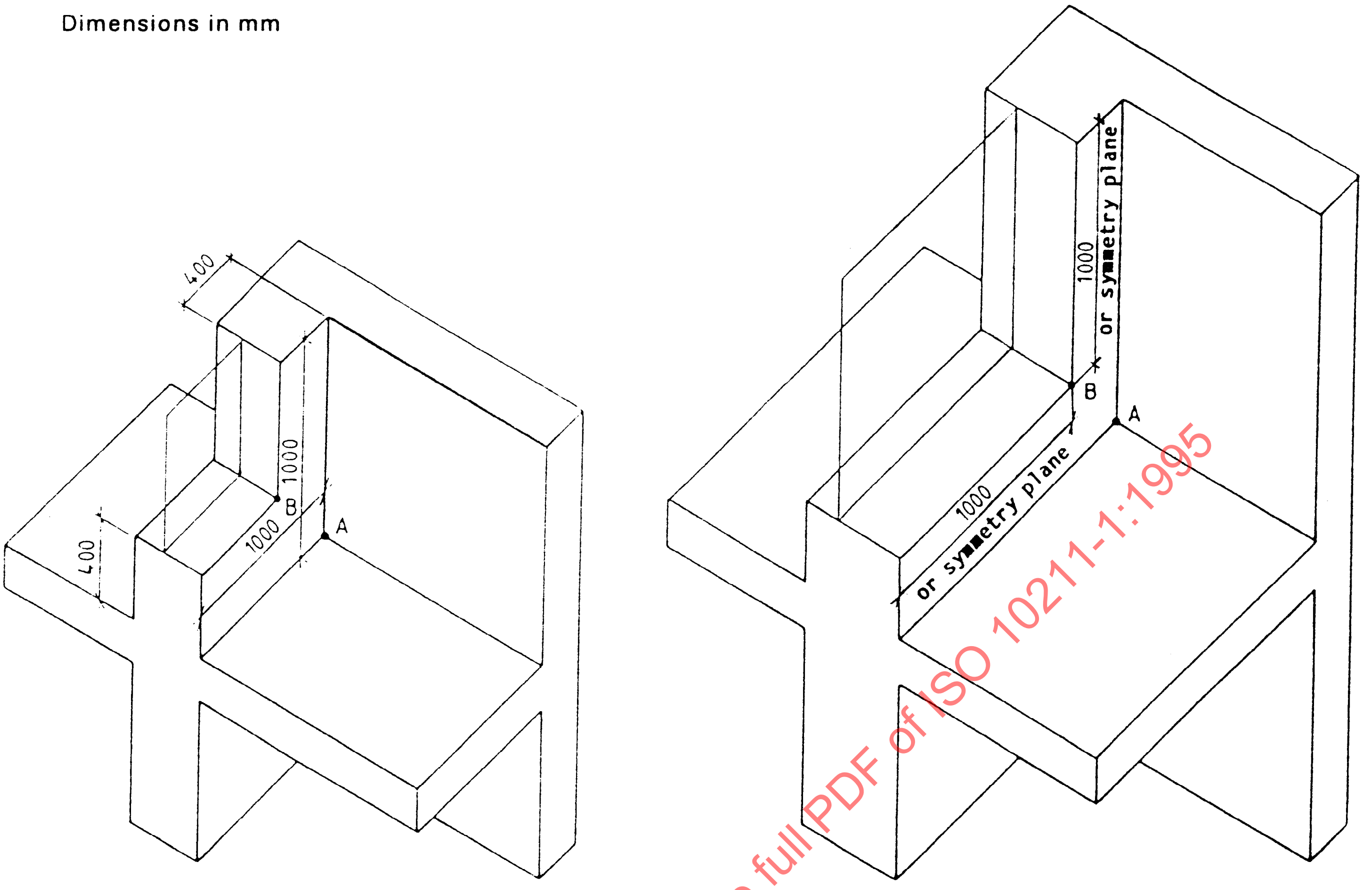


Figure 6: Two thermal bridges A and B in the same model.The thermal bridge nearest to the cut-off planes does not fulfil the condition of being at least 1 m from a cut-off plane (left). This difficulty is avoided by extending the model in two directions (right)

Table 1: Location of cut-off planes in the subsoil
(foundations, ground floors, basements)

Distance to central element in metres

Direction	Purpose of the calculation	
	Surface temperatures, see figure 7a	heat flow, see figure 7b
Horizontal inside the building	at least 1 m	0,5 b
Horizontal outside the building	same distance as inside the building	2,5 b
Vertical below ground level	3 m	2,5 b
Vertical below floor level (see Note)	1 m	-
where: b is the width (the smaller dimension) of the ground floor in metres.		

NOTE: This value applies only if the level of the floor under consideration is more than 2 m below the ground level.

Dimensions in mm

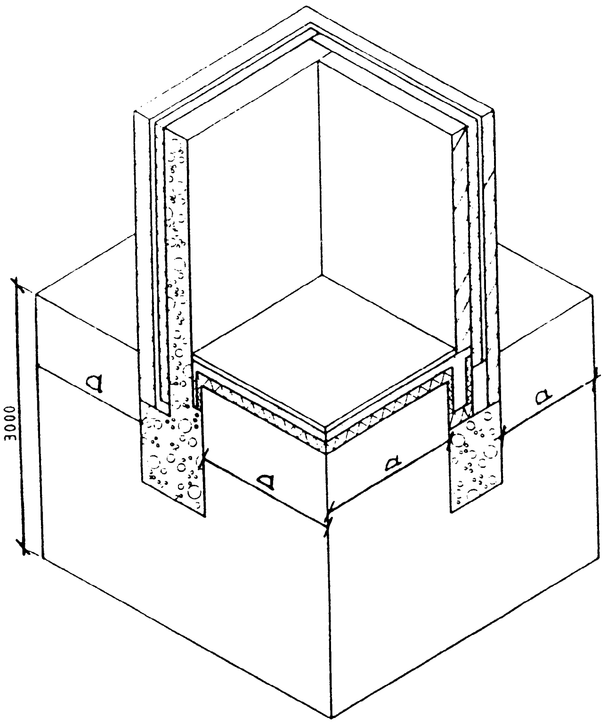


Figure 7a: Soil dimensions - calculation of surface temperatures

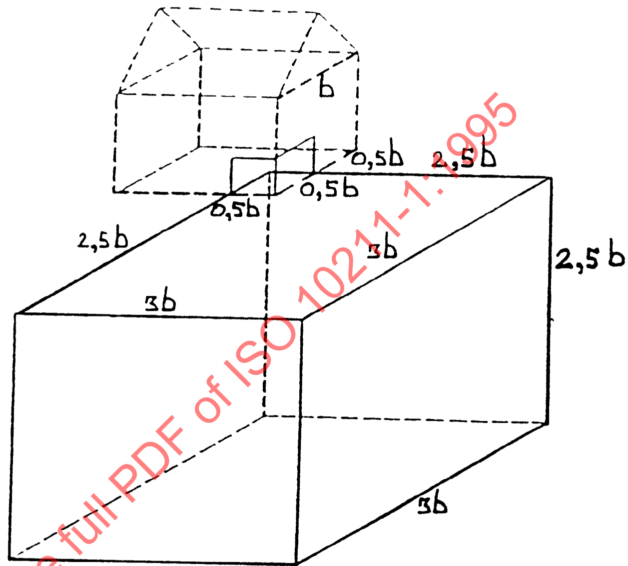


Figure 7b: Soil dimensions - calculation of heat flow

5.1.2 Adjustments to dimensions

Adjustments to the dimensions of the geometrical model with respect to the actual geometry are allowed if they have no significant influence on the result of the calculation; this can be assumed if the conditions in 5.2.1 are satisfied.

5.1.3 Auxiliary planes

The number of auxiliary planes in the model shall be such that adding more auxiliary planes does not change the temperature difference ratios ζ_{Rsi} by more than 0,005 (see also A.2).

NOTE: A guideline for fulfilling this requirement in many cases is (see figure 8a):
The distances between adjacent parallel planes should not exceed the following values:
- within the central element 25 mm
- within the flanking elements, measured from the construction plane which separates the central element from the flanking element:
25, 25, 50, 50, 50, 100, 200, 500, 1000, 2000 and 4000 mm.

For constructions with indentations of small dimensions (e.g. window profiles) a finer subdivision will be needed (see figure 8b).

Dimensions in mm

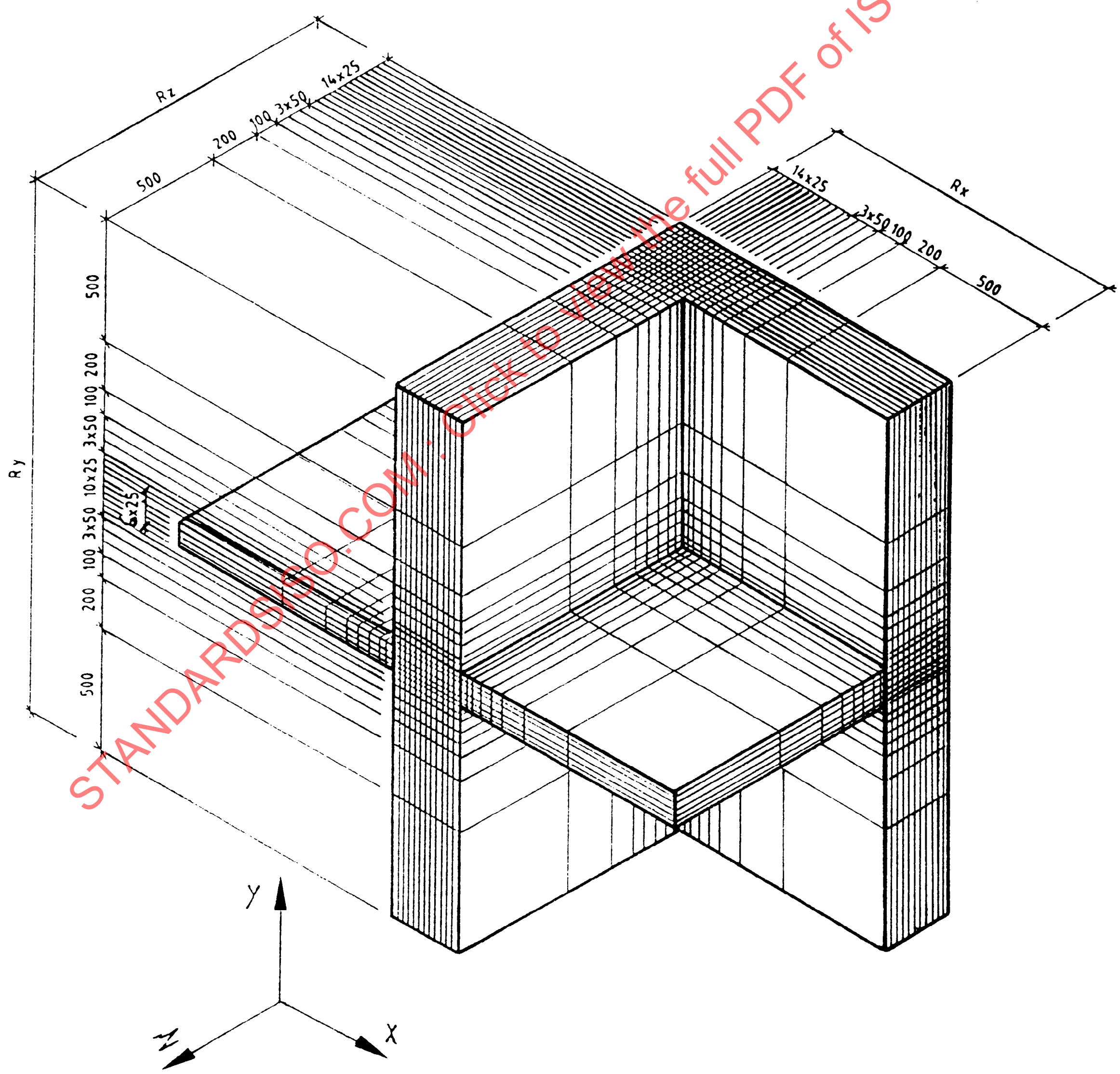


Figure 8a: Example of construction planes supplemented with auxiliary planes

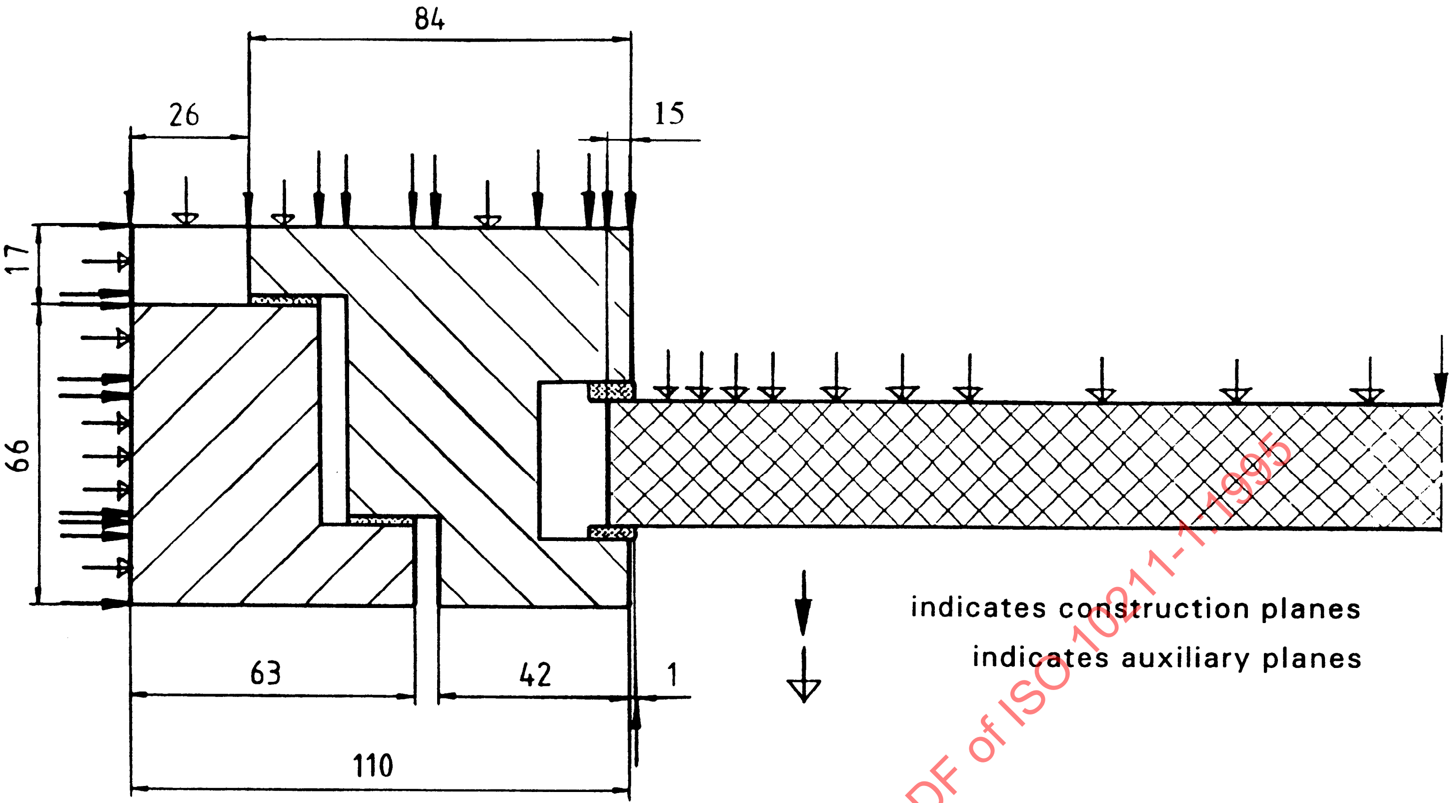


Figure 8b: Example of construction planes and auxiliary planes in the 2-D geometrical model of a window frame

5.1.4 Quasi-homogeneous layers and materials

In a geometrical model materials with different thermal conductivities may be replaced by a material with a single thermal conductivity if the conditions in 5.2.2 are satisfied.

> **NOTE:** Examples are joints in masonry, wall-ties in thermally insulated cavities, screws in wooden laths, roof tiles and the associated air cavity and tile battens.

5.2 *Conditions for simplifying the geometrical model*

Calculation results obtained from a geometrical model with no simplifications shall have precedence over those obtained from a geometrical model with simplifications.

The following adjustments can be made.

> **NOTE:** This is important when the results of a calculation are close to any required value.

5.2.1 Conditions for adjusting dimensions to simplify the geometrical model

Adjustment to the dimensions may be made only to materials with thermal conductivity less than 3 W/(m · K).

a) *Change in the location of the surface* of a block of material adjacent to the internal or external surface of the geometrical model (see figure 9): the local adjustment d_{corr} to the location of surfaces which are not flat, relative to the mean location of the surface, shall not exceed:

$$d_{corr} = R_{corr} \lambda$$

where:

d_{corr} is the local adjustment perpendicular to the mean location of the internal or external surface;

R_{corr} is equal to 0,03 $m^2 \cdot K/W$;

λ is the thermal conductivity of the material in question.

NOTE: Examples are inclined surfaces, rounded edges and profiled surfaces, such as roof tiles.

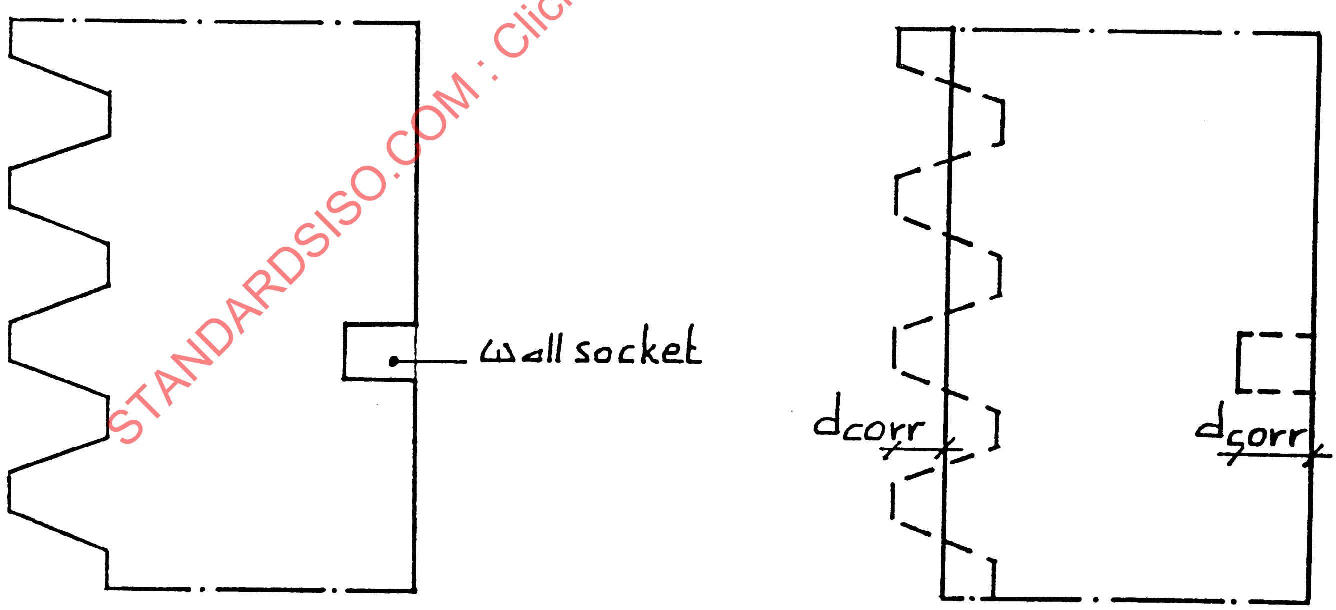
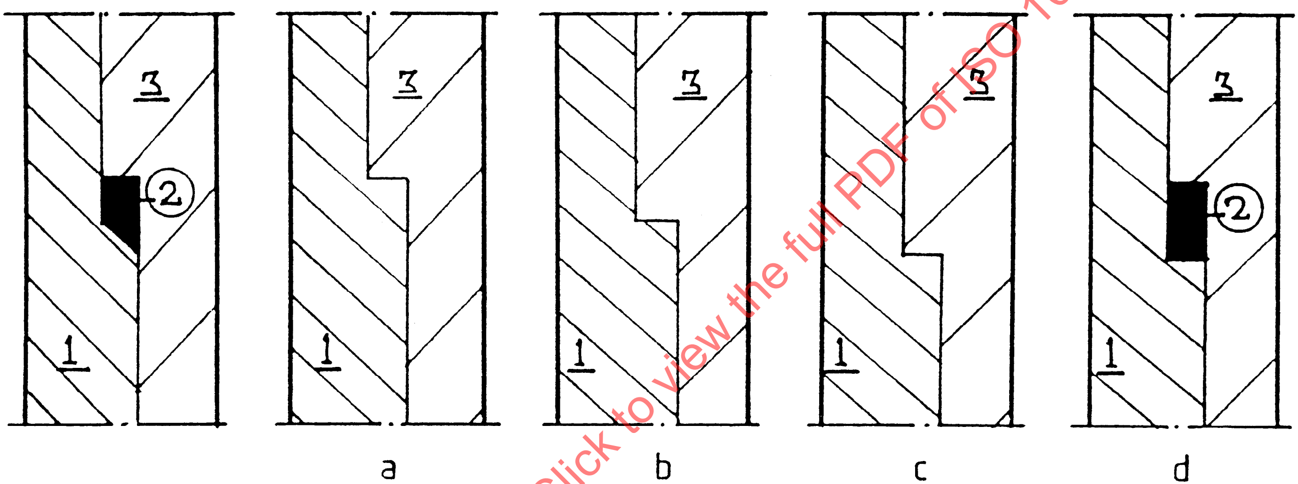


Figure 9: Change in the location of the internal or external surface

b) ***Change in the interface*** of two regions of different material:

- the relocation of the interface shall take place in a direction perpendicular to the internal surface;
- the relocation of the interface shall be such that the material with the lower thermal conductivity is replaced by the material with the higher thermal conductivity (see figure 10).

NOTE: Examples are recesses for sealing strips, kit joints, adjusting blocks, wall sockets, inclined surfaces and other connecting details.



combination **simplifications**

Material block	Thermal conductivity	Simplification			
		a	b	c	d
1	λ_1	$\lambda_1 > \lambda_2$	$\lambda_1 > \lambda_3$	$\lambda_1 < \lambda_3$	$\lambda_1 < \lambda_2$
2	λ_2				
3	λ_3		$\lambda_3 > \lambda_2$	$\lambda_3 > \lambda_2$	$\lambda_3 < \lambda_2$

Figure 10: Four possibilities for relocating the interface between three material blocks, depending on the ratio of their thermal conductivities

c) ***Neglecting thin layers:***
- layers with a thickness of not more than 1 mm may be ignored;

NOTE: Examples are non-metal membranes which resist the passage of moisture or water vapour.

d) ***Neglecting appendages*** attached to the outside surface:
- components of the building which have been attached to the outside surface (i.e. attached at discrete points).

NOTE: Examples are rainwater gutters and discharge pipes.

5.2.2 Conditions for using quasi-homogeneous material layers to simplify the geometrical model

The following conditions for incorporating minor linear and point thermal bridges into a quasi-homogeneous layer apply in all cases:

- the layers of material in question are located in a part of the construction which, after simplification, becomes a flanking element;

- the thermal conductivity of the quasi-homogeneous layer after simplification is not more than 1,5 times the lowest thermal conductivity of the materials present in the layer before simplification.

a) ***Calculation of the thermal coupling coefficient L***

The thermal conductivity of the quasi-homogeneous layer shall be calculated according to equation (1):

$$\lambda' = \frac{d}{\frac{A}{L} - R_{si} - R_{se} - \Sigma \frac{d_j}{\lambda_j}} \qquad (1)$$

where:

λ'	is the effective thermal conductivity of the quasi-homogeneous layer;
d	is the thickness of the thermally inhomogeneous layer;
A	is the area of the building component;
L	is the thermal coupling coefficient of the building component determined by a 2-D or 3-D calculation;
d_j	are the thicknesses of the homogeneous layers which are part of the construction;
λ_j	are the thermal conductivities of these homogeneous layers.

NOTE: The use of equation (1) is appropriate if a number of identical minor thermal bridges are present (wall-ties, joints in masonry, hollow blocks etc.). The calculation of L can be restricted to a basic area which is representative of the inhomogeneous layer. For instance a cavity wall with 4 wall-ties per square metre can be represented by a basic area of 0,25 m² with one wall-tie.

b) ***Calculation of the internal surface temperature and the linear thermal transmittance Ψ or the point thermal transmittance χ (see annex C)***

The thermal conductivity of the quasi-homogeneous layer may be taken as:

$$\lambda' = \frac{(\lambda_o A_o + \ldots\ldots + \lambda_n A_n)}{(A_o + \ldots\ldots + A_n)} \qquad (2)$$

where:

- λ' is the effective thermal conductivity of the quasi-homogeneous layer;
- λ_o .. λ_n are the thermal conductivities of the constituent materials;
- A_o .. A_n are the areas of the constituent materials measured in the plane of the layer;

provided that:

- the thermal bridges in the layer under consideration are at or nearly at right angles to the internal or external surface of the constructions and penetrate the layer over its entire thickness;

- the thermal resistance (surface to surface) of the construction after simplification is at least 1,5 (m² · K)/W;

- the conditions of at least one of the groups stated in table 2 are met (see figure 11).

Table 2: Specific conditions for incorporating linear or point thermal bridges in a quasi-homogeneous layer

Group (see figure 11)	λ_{tb} W/(m·K)	A_{tb} m²	R_o m²·K/W	$R_{t,i}$ m²·K/W	λ_i W/(m·K)	d_i m
1	≤ 1,5	≤ 0,05.l_{tb}	≤ 0,5	-	-	-
2	> 3	≤ 30 x 10^{-6}	≤ 0,5	-	-	-
3	> 3	≤ 30 x 10^{-6}	> 0,5	≥ 0,5	-	-
4	> 3	≤ 30 x 10^{-6}	> 0,5	< 0,5	≥ 0,5	≥ 0,1

where:

λ_{tb} is the thermal conductivity of the thermal bridge to be incorporated in the quasi-homogeneous layer;

A_{tb} is the area of the cross section of the thermal bridge;

l_{tb} is the length of a linear thermal bridge;

R_o is the thermal resistance of the layer without the presence of the point thermal bridge;

$R_{t,i}$ is the total thermal resistance of the layers between the quasi-homogeneous layer considered and the internal surface;

λ_i is the thermal conductivity of the material layer between the quasi-homogeneous layer considered and the internal surface with the highest value of λ_i times d_i;

d_i is the thickness of the same layer.

NOTE: Group 1 includes linear thermal bridges. Examples are joints in masonry, wooden battens in air cavities or in insulated cavities of minor thickness.

Group 2 includes such items as wall-ties insofar as they are fitted in masonry or concrete or are located in an air cavity, as well as nails and screws in layers of material or strips with the indicated maximum thermal resistance.

Groups 3 and 4 include such items as cavity ties insofar as they penetrate an insulation layer which has a higher thermal resistance than that indicated for group 2. The inner leaf must then have thermal properties which sufficiently limit the influence of the thermal bridge on the internal surface temperature. This may be the case if the inner leaf has a sufficient thermal resistance (group 3) or the thermal conductivity of the inner leaf is such that the heat flow through the cavity ties is adequately distributed over the internal surface; most masonry or concrete inner leaves are examples of group 4.

Calculation examples are given in annex D.

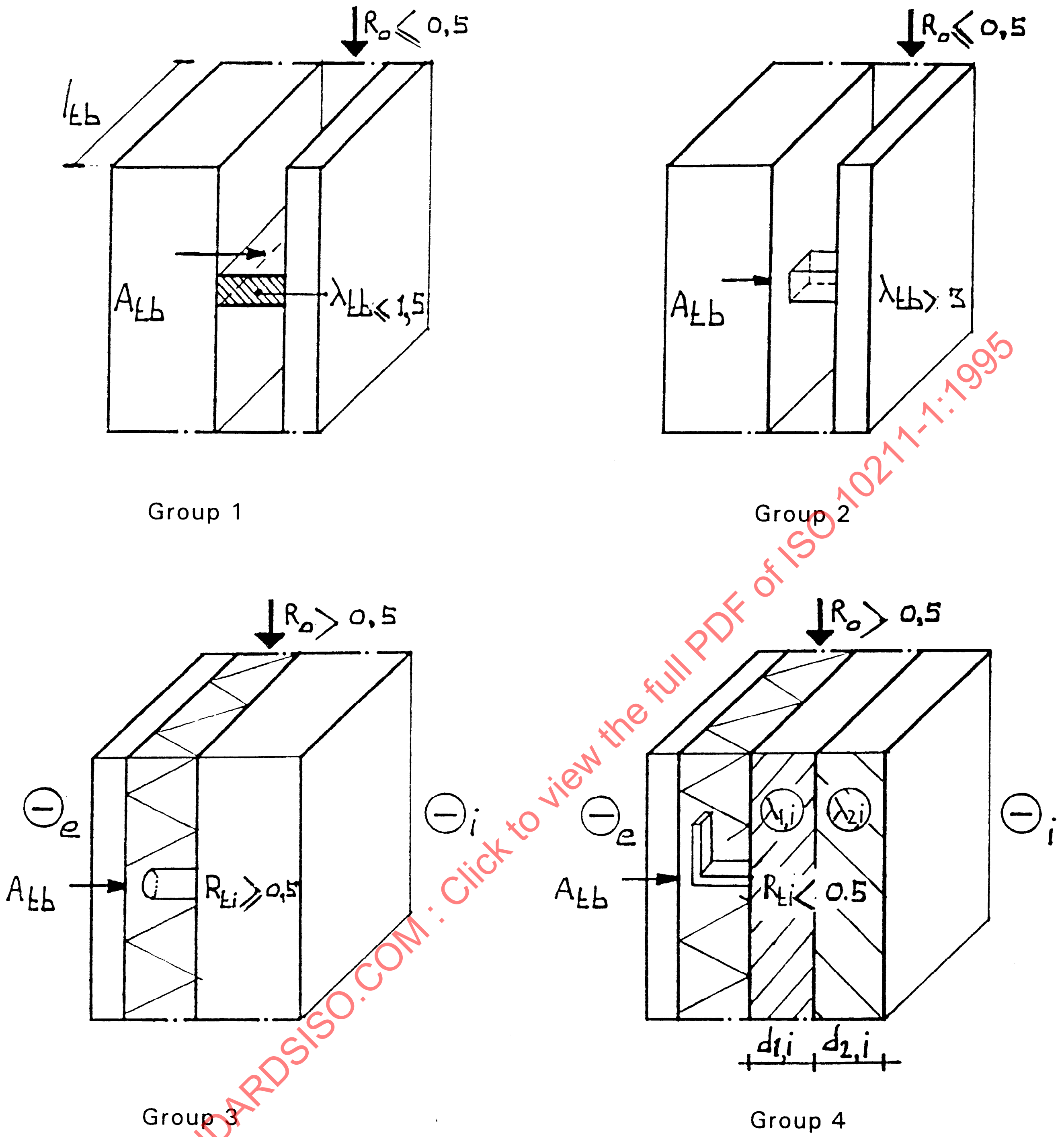


Figure 11: Specific conditions for incorporating linear and point thermal bridges in a quasi-homogeneous layer for the groups given in table 2

6 Calculation values

6.1 *Given calculation values*

Use the values given in this subclause unless non-standard values are justified for a particular situation.

NOTE: Non-standard values may be justified by local conditions (e.g. established temperature distributions in the ground) or by specific material properties (e.g. the effect of a low emissivity coating on the surface resistance).

6.1.1 Thermal conductivities of materials

The design values of thermal conductivities of building materials and products should either be calculated according to prEN 30456 or taken from tabulated values.

The thermal conductivity of soil can be taken as 2,0 W/(m·K)

NOTE: Other values for the thermal conductivity of the soil may be used if information on the local soil condition is available. See prEN 1190.

6.1.2 Surface resistances

The values according to table 3 shall be applied.
For heat flow calculations the value of R_{si} is related to the internal mean dry resultant temperature.

For the calculation of surface temperatures the value of R_{si} is related to the mean internal air temperature, but shall take account of the non-uniform air temperature due to thermal stratification and the non-uniform radiant temperature that exists in edges and corners.

NOTE: When calculating the surface temperature, the following values for the internal surface resistance are recommended:
Glazing: 0,13 m²·K/W
Upper half of the room: 0,25 m²·K/W
Lower half of the room: 0,35 m²·K/W
The value of R_{si} = 0,50 m²·K/W is recommended if significant thermal shielding by objects such as furniture may occur. See annex E.

Table 3: Surface resistances (m²·K/W)

	Purpose of calculation	
	Surface temperatures	Heat flow rate
External surface resistance R_{se}	0,04	0,04
Internal surface resistance R_{si}	[1])	0,13
[1]) See Annex E		

6.1.3 Boundary temperatures

Table 4 gives the boundary temperatures which shall be used.

Table 4: Boundary temperatures

	Purpose of calculation	
	Surface temperature	Heat flow rate
Internal	air temperature	dry resultant temperature
Internal in unheated rooms	see 6.2.3	see 6.2.3
External	air temperature, assuming that the sky is completely overcast	air temperature, assuming that the sky is completely overcast
Soil (horizontal cut-off plane)	at the distance below ground level given in table 1: yearly average external air temperature	at the distance below ground level given in table 1: adiabatic boundary condition

6.2 *Methods of determining the calculation values*

6.2.1 Thermal conductivity of quasi-homogeneous layers

The thermal conductivity of quasi-homogeneous layers shall be calculated according to equations (1) and (2).

6.2.2 Equivalent thermal conductivity of air cavities

An air cavity shall be considered as a homogeneous conductive material with a thermal conductivity λ_{cav}.

If the thermal resistance of an air layer or cavity is known, the thermal conductivity is obtained from:

$$\lambda_{cav} = \frac{d_{cav}}{R_{cav}} \tag{3}$$

where:

λ_{cav} is the thermal conductivity of the air layer or cavity;

d_{cav} is the thickness of the air layer;

R_{cav} is the thermal resistance in the main direction of heat flow.

Thermal resistances and thermal conductivities of air layers and cavities bounded by opaque materials are given in annex B.

For the thermal resistance of air layers in multiple glazing see prEN 673.

NOTE: Air cavities with dimensions of more than 0,5 m along each one of the orthogonal axis shall be treated as rooms (see 6.2.3).

6.2.3 Determining the temperature in an adjacent unheated room

If sufficient information is available, the temperature in an adjacent unheated room may be calculated according to prEN 33789.

If the temperature in an adjacent unheated room is unknown and cannot be calculated according prEN 33789, because the necessary information is not available, the heat flows and internal surface temperatures can not be calculated. However all required coupling coefficients and temperature weighting factors can be calculated and presented according to annex F.

NOTE: When assessing the thermal behaviour of thermal bridges, the available information is usually restricted to a specific part of the construction (e.g. junctions) and little or no information is available on dimensions or on the total coupling coefficients of the adjacent room.

7 Calculation method

The geometrical model is divided into a number of cells, each with a characteristic point (called a node). By applying the laws of energy conservation ($div\ q = 0$) and Fourier ($q = -\lambda \cdot grad\ \Theta$) and taking into account the boundary conditions, a system of equations is obtained which is a function of the temperatures at the nodes. The solution of this system, either by a direct solution technique or by an iterative method, provides the node temperatures from which the temperature field can be determined. From the temperature distribution, the heat flows can be calculated by applying Fourier's law.

Calculation programs shall be verified according to the requirements of annex A.

7.1 *Calculation rules*

7.1.1 Heat flows between material cells and adjacent environment

The density of heat flow rate, perpendicular to the interface between a material cell and the adjacent environment shall satisfy:

$$q = \frac{(\Theta - \Theta_s)}{R_s} \qquad (4)$$

where:

- q is the density of heat flow rate;
- Θ is the internal or external reference temperature;
- Θ_s is the temperature at the internal or external surface;
- R_s is the internal or external surface resistance.

7.1.2 Heat flows at cut-off planes

The cut-off planes shall be adiabatic (i.e. zero heat flow) with the exception given in 6.1.3.

NOTE: In the case of calculating surface temperatures, the horizontal cut-off plane in the soil is not adiabatic, but has a fixed temperature.

7.1.3 Solution of the equations

The equations shall be solved according to the requirements given in A.2.

7.1.4 Calculation of the temperature distribution

The temperature distribution within each material cell shall be calculated by interpolation between the node temperatures.

NOTE: Linear interpolation suffices.

7.2 *Determination of the thermal coupling coefficients and the heat flow rate*

7.2.1 More than two boundary temperatures

The heat flow rate $\Phi_{i,j}$ from environment i to a thermally connected environment j is given by:

$$\Phi = L_{i,j}(\Theta_i - \Theta_j) \qquad (5)$$

The total heat flow rate from a room or building can be calculated using the principles as stated in clause 4. For more than two environments with different temperatures (e.g. different internal temperatures or different external temperatures), the total heat flow rate **Φ** of the room or the building can be calculated from:

$$\Phi = \Sigma \{ L_{i,j}(\Theta_i - \Theta_j) \} \quad (6)$$

where $L_{i,j}$ are the total coupling coefficients between each pair of environments.

NOTE: F.1 gives a method to calculate the thermal coupling coefficients.

7.2.2 Two boundary temperatures, unpartitioned model

If there are only two environments with two different temperatures (e.g. one internal and one external temperature), and if the total room or building is calculated 3-dimensionally from a single model, then the total thermal coupling coefficient $L_{1,2}$ can be obtained from the total heat flow rate **Φ** of the room or building:

$$\Phi = L_{1,2}\ (\Theta_1 - \Theta_2) \quad (7)$$

7.2.3 Two boundary temperatures, partitioned model

If the room or building has been partitioned (see figure 12), the total $L_{i,j}$-value is calculated from (8):

$$L_{i,j} = \sum_{n=1}^{N} L^{3D}_{n(i,j)} + \sum_{m=1}^{M} L^{2D}_{m(i,j)} \cdot l_m + \sum_{k=1}^{K} U_{k(i,j)} \cdot A_k \quad (8)$$

where:

$L^{3D}_{n(i,j)}$ is the thermal coupling coefficient obtained from a 3-D calculation for part n of the room or building;

$L^{2D}_{m(i,j)}$ is the linear thermal coupling coefficient obtained from a 2-D calculation for part m of the room or building;

l_m is the length over which the value $L^{2D}_{m(i,j)}$ applies;

$U_{k(i,j)}$ is the thermal transmittance obtained from a 1-D calculation for part k of the room or building;

A_k is the area over which the value U_k applies;

N is the total number of 3-D parts;

M is the total number of 2-D parts;

K is the total number of 1-D parts.

NOTE: In formula (8) ΣA_k is less than the total surface area of the envelope.

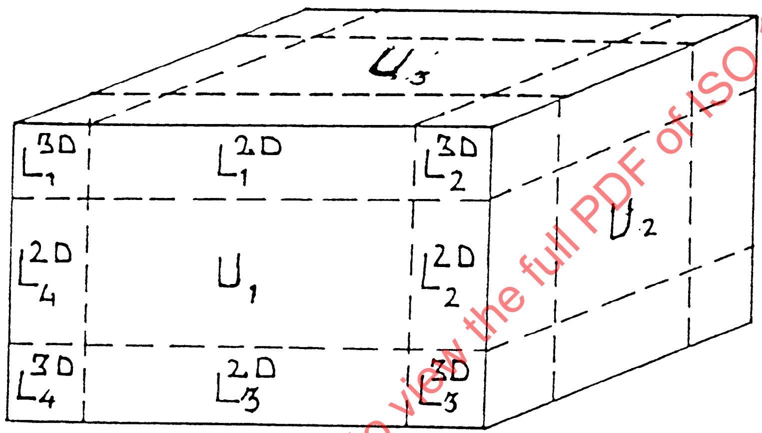


Figure 12: Building envelope partitioned into 3-D, 2-D and 1-D geometrical models

7.3 *Determination of the temperature at the internal surface*

7.3.1 More than two boundary temperatures

If there are more than two boundary temperatures, the temperature weighting factor g shall be used. The temperature weighting factors provide the means to calculate the temperature at any location at the inner surface with coordinates (x,y,z) as a linear function of any set of boundary temperatures.

NOTE 1: At least three boundary temperatures are involved if the geometrical model includes internal environments with different temperatures and also if the subsoil is part of the geometrical model (see 6.1.3).

Using the temperature weighting factors, the surface temperature at location (x,y,z) is given by:

$$\Theta_{x,y,x} = g_1(x,y,z)\ \Theta_1 + g_2(x,y,z)\ \Theta_2\ \ldots. + g_n(x,y,z)\ \Theta_n \qquad (9)$$

with:

$$g_1(x,y,z) + g_2(x,y,z) + \ldots. + g_n(x,y,z) = 1 \qquad (10)$$

NOTE 2: F.3 gives a method for calculating the weighting factors.

Calculate the internal surface temperature $\boldsymbol{\Theta}_{si}$ at the location of interest by inserting the calculated values of $\boldsymbol{g}_i$ and the actual boundary temperatures $\boldsymbol{\Theta}_i$ in equation (9).

NOTE 3: Normally the location of interest is the point with the lowest internal surface temperature. This location may vary if the boundary temperatures are changed.

7.3.2 Two boundary temperatures

If there are only two environments involved and the subsoil is not a part of the geometrical model, the surface temperatures can be expressed in a dimensionless form according to formula (11) or (12):

$$\zeta_{Rsi}(x,y,z) = \frac{\Theta_i - \Theta_{si}(x,y,z)}{(\Theta_i - \Theta_e)} \qquad (11)$$

or:

$$f_{Rsi}(x,y,z) = \frac{\Theta_{si}(x,y,z) - \Theta_e}{(\Theta_i - \Theta_e)} \qquad (12)$$

where:

- $\zeta_{Rsi}(x,y,z)$ is the temperature difference ratio at the internal surface at point (x,y,z);
- $f_{Rsi}(x,y,z)$ is the temperature factor at the internal surface at point (x,y,z);
- $\Theta_{si}(x,y,z)$ is the temperature at the internal surface at point (x,y,z);
- Θ_i is the internal air temperature;
- Θ_e is the external air temperature.

The temperature difference ratio or temperature factor shall be calculated with an error of less than 0,005.

8 Input and output data

8.1 Input data

The report of the calculation shall contain the following information:

a) ***Description of structure:***
- building plans including dimensions and materials;
- for a completed building, any known alterations to the construction and/or physical measurements and details from inspection;
- other relevant remarks.

b) ***Description of the geometrical model:***
- 3-D model with dimensions;
- input data which show the location of the construction planes and any auxiliary planes together with the thermal conductivities of the various materials;
- the applied boundary temperatures;
- a calculation of the boundary temperature in an adjacent area when appropriate;
- the surface resistances and the areas to which they apply;
- any dimensional adjustments according to 5.2.1;
- any quasi-homogeneous layers and the thermal conductivities calculated according to 5.2.2;
- any non-standard values used with justification of the deviation from standard values.

NOTE: See 6.1.

8.2 Output data

The following calculation results shall be reported as values which are independent of the boundary temperatures:

- thermal coupling coefficient L between adjacent rooms involved in heat transfer through the building components;

NOTE 1: An example is given in table F.2.

- temperature factor f_{Rsi} or temperature difference ratio ζ_{Rsi} for the points of lowest surface temperatures in each room involved (including the location of these points); if more than two boundary temperatures are used, the temperature weighting factors shall be reported.

NOTE 2: An example how to report temperature weighting factors is given in table F.4.

All output values shall be given to at least three significant figures.

8.2.1 *Calculation of the heat transmission using the thermal coupling coefficient*

The heat transmission from environment i to environment j is given by equation (5) if there are more than two boundary temperatures and equation (6) if there are two boundary temperatures (see 7.2).

8.2.2 *Calculation of the surface temperatures using weighting factors*

The lowest internal surface temperature exposed to room j is given by equation (9) (see 7.3):

$$\theta_{s,j_{min}} = g_{1,j}\,\theta_1 + g_{2,j}\,\theta_2 + \ldots\ldots + g_{n,j}\,\theta_n \qquad (13)$$

8.2.3 *Additional output data*

For a specific set of boundary temperatures the following additional values shall be presented:

- heat flow rates in watts per square metre (for 2-D cases) or watts (for 3-D cases) for each pair of rooms of interest;
- minimum surface temperatures in degrees Celsius and the location of the points with minimum surface temperature in each room of interest.

8.2.4 *Estimate of error*

Numerical procedures give approximate solutions which converge to analytical solutions, if one exists. In order to evaluate the reliability of the results the residual error should be estimated.

- In order to estimate errors due to insufficient numbers of cells additional calculation(s) shall be made according to A.2. The difference in results for both calculations shall be stated.

- In order to estimate errors arising in the numerical solution of the equation system, the sum of heat flows (positive and negative) over all boundaries of the building component divided by the total heat flow shall be given.

NOTE: A.2 specifies that this quotient is to be less than 0,001.

Annex A (normative)

Validation of calculation methods

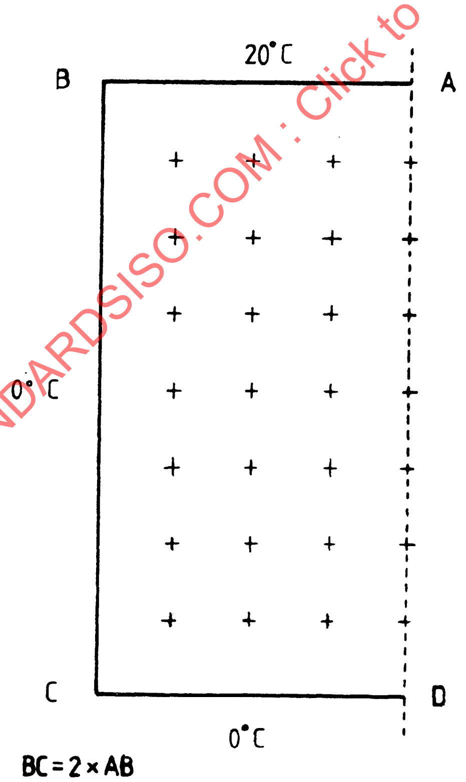
This annex specifies the validation procedure for high precision calculation methods for thermal bridges.

A.1 Test reference cases

In order to be classified as a three-dimensional steady-state high precision method, it shall give results corresponding with those of the test reference case 1, 2 and 3, represented respectively in figures A.1, A.2 and A.3.

In order to be classified as a two-dimensional steady-state high precision method, it shall give results corresponding with those of the test reference case 1 and 2, represented respectively in figures A.1 and A.2.

Case 1 (figure A.1):
The heat transfer through half a square column, with known surface temperatures (see figure A.1), can be calculated analytically. The analytical solution at 28 points of an equidistant grid is given in the same figure. The difference between the temperatures calculated by the method being validated and the temperatures listed, shall not exceed 0,1 K.



Analytical solution at grid nodes

9,7	13,4	14,7	15,1
5,3	8,6	10,3	10,8
3,2	5,6	7,0	7,5
2,0	3,6	4,7	5,0
1,3	2,3	3,0	3,2
0,7	1,4	1,8	1,9
0,3	0,6	0,8	0,9

Figure A.1: Test reference case 1: comparison with the analytical solution

Case 2 (figure A.2):

An example of two-dimensional heat transfer is given in figure A.2. The temperatures at some particular points and the heat flow through the total object (with a length of 1 m perpendicular to the section) are represented in the same figure. The difference between the temperatures calculated by the method being validated and the temperatures listed, shall not exceed 0,1 K. The difference between the heat flow calculated by the method being validated and the heat flow listed, shall not exceed 0,1 W/m.

Discription of the model

Geometry (mm)	Thermal conductivities W/(m·K)	Boundary conditions
AB = 500	1: 1,15	AB: 0 °C with R_{se} = 0,06 m²·K/W
AC = 6	2: 0,12	HI: 20 °C with R_{si} = 0,11 m²·K/W
CD = 15	3: 0,029	
CF = 5	4: 230	
EM = 40		
GJ = 1,5		
IM = 1,5		
FG-KJ = 1,5		

Numerical solution temperatures in °C:

Total heat flow rate: 9,5 W/m

A: 7,1		B: 0,8
C: 7,9	D: 6,3	E: 0,8
F: 16,4	G: 16,3	
H: 16,8		I: 18,3

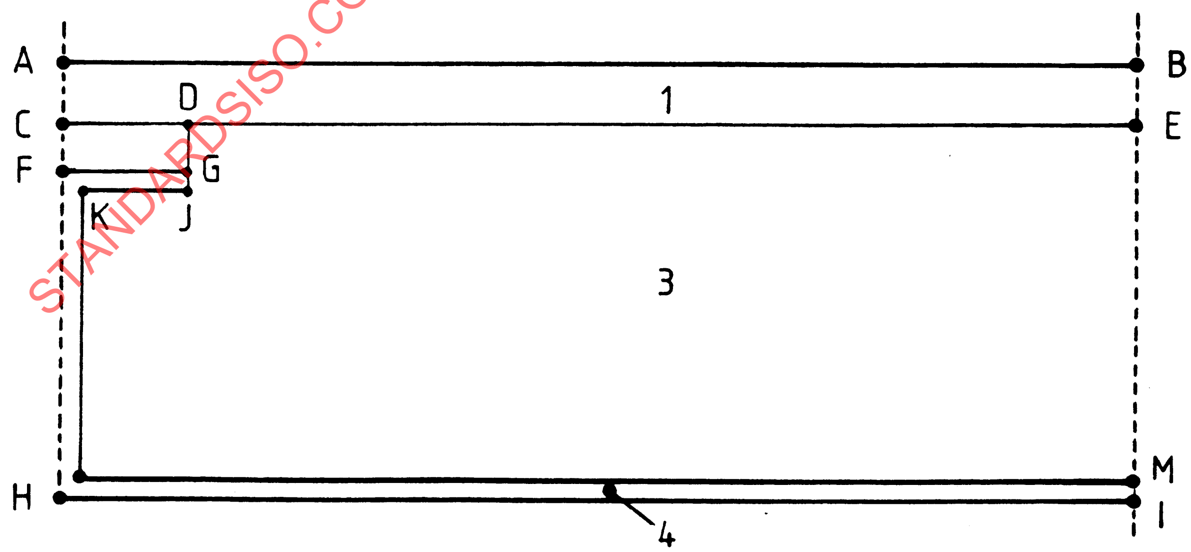


Figure A.2: Test reference case 2: comparison with a 2-D calculation

Case 3 (figure A.3):

An example of a three-dimensional heat transfer is given in figure A.3. The temperatures at some particular points and the heat flows to or from the three environments considered are represented in the same figure. The difference between the temperatures calculated by the method being validated and the temperatures listed shall not exceed 0,1 K. The difference between the heat flows calculated by the method being validated and the heat flows listed, shall not exceed 2% of the listed values.

Discription of the model

Geometry
mm

AB = 1300
BD = HI = 100
DE = IJ = 50
EF = JK = 150
FL = KL = 1000
CG = 1150
GH = 600
MP = ST = 1000
QR = 50
RS = 150
NQ = 950
OP = 600

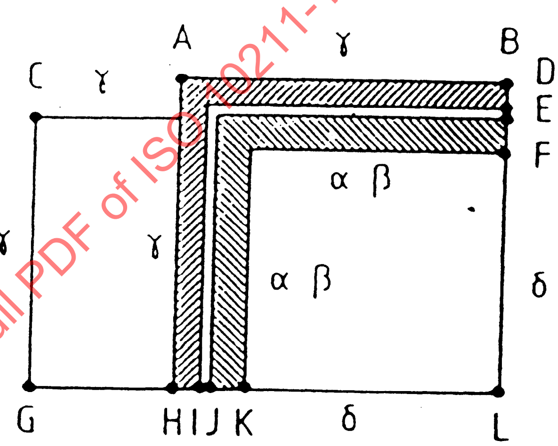
Thermal conductivities
W/(m·K)

1: 0,7
2: 0,04
3: 1,0
4: 2,5
5: 1,0

boundary conditions:

α: 20°C 0,20 m²·K/W
β: 15°C 0,20 m²·K/W
γ: 0°C 0,05 m²·K/W
δ: adiabatic

Horizontal section



Numerical solution

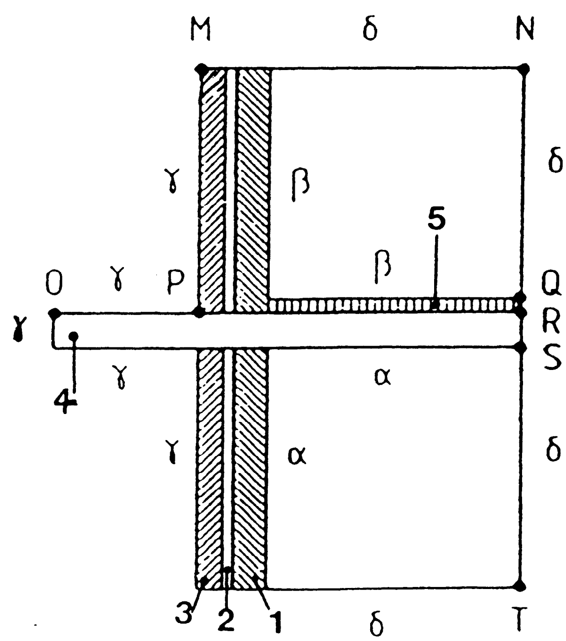
Temperatures in, °C:

U: 12,9 X: 12,6
V: 11,3 Y: 11,1
W: 16,4 Z: 15,3

Heat flows, in W:

α loss = 46,3
β loss = 14,0
γ gain = 60,3

Vertical section



Perspective

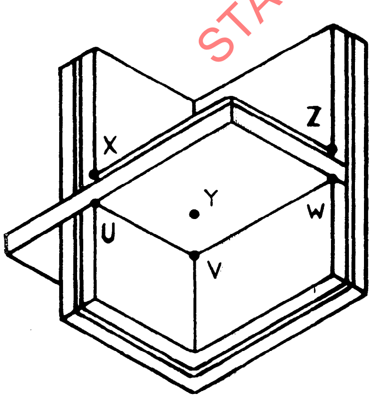


Figure A.3: Test reference case 3: comparison with a 3-D calculation

A.2 General considerations and requirements for calculation methods

High precision calculation methods are known as numerical methods (finite element method, finite difference method, heat balance method, ...). These numerical methods require a subdivision of the object considered. The method is a set of rules to form a system of equations, the number of which is proportional to the number of subdivisions. The system is solved using either a direct solution method or an iterative method. From the solution of the system, normally the temperatures at specific points, the temperatures at any point of the object considered can be derived (by interpolation); also the heat flows through specific surfaces can be derived.

The numerical method being validated has to meet the following requirements:

a) The method shall provide temperatures and heat flows.

b) The extent of subdivision of the object (i.e. the number of cells, nodes) is not 'method defined' but 'user defined', although in practice the degree of subdivision is 'machine limited'. Therefore, in the test reference cases, the method being validated shall be able to calculate temperatures and heat flows at locations other than those listed.

c) For an increasing number of subdivisions, the solution of the method being validated shall converge to the analytical solution if such a solution exists (e.g. test reference case 1).

NOTE: For an increasing number of subdivisions the solution converges. The number of subdivisions required to obtain good accuracy depends on the problem considered.

d) The number of subdivisions shall be determined as follows: the sum of the absolute values of all the heat flows entering the object is calculated twice: for n subdivisions and for 2n subdivisions. The difference between these two results shall not exceed 2%. If not, further subdivisions shall be made until this criterion is met.

e) If the system solution technique is iterative, the iteration shall continue until the sum of all heat flows (positive and negative) entering the object, divided by half the sum of the absolute values of all these heat flows, is less than 0,001.

Annex B (normative)

Equivalent thermal conductivity of air cavities

B.1 General

This annex applies to air cavities bounded by opaque materials with:

- emissivity of each surface ≥ 0,80;
- a mean temperature of approximately 10 °C;
- a temperature difference between the internal surfaces up to 5 K for air cavities in constructions with a relatively low thermal transmittance;
- a temperature difference between the internal surfaces of 8k to 12 K for air spaces in constructions with a relatively high thermal transmittance (e.g. window profiles).

NOTE: In the case of internal surfaces with a lower emissivity the thermal resistance is higher than the values given in table B.1 and the thermal conductivity is lower than the values given in table B.2 and B.3. See prEN ISO 6946-1.

B.2 Thermal resistance of air layers and cavities in constructions with a relatively low thermal transmittance

The thermal resistances of unventilated air layers and tube-shaped cavities with a mean thermal transmittance less than 1,0 W/(m^2·K) are given in table B.1.

The dimensions of d and b relative to the heat flow direction are shown in figure B.1.

The equivalent thermal conductivity shall be calculated according to equation (3).

The design thermal resistance of a slightly ventilated air layer is one half of the corresponding value in table B.1. For well ventilated air layers see prEN ISO 6946-1.

NOTE: The definitions of unventilated, slightly ventilated and well ventilated air-layers are given in prEN ISO 6946-1.

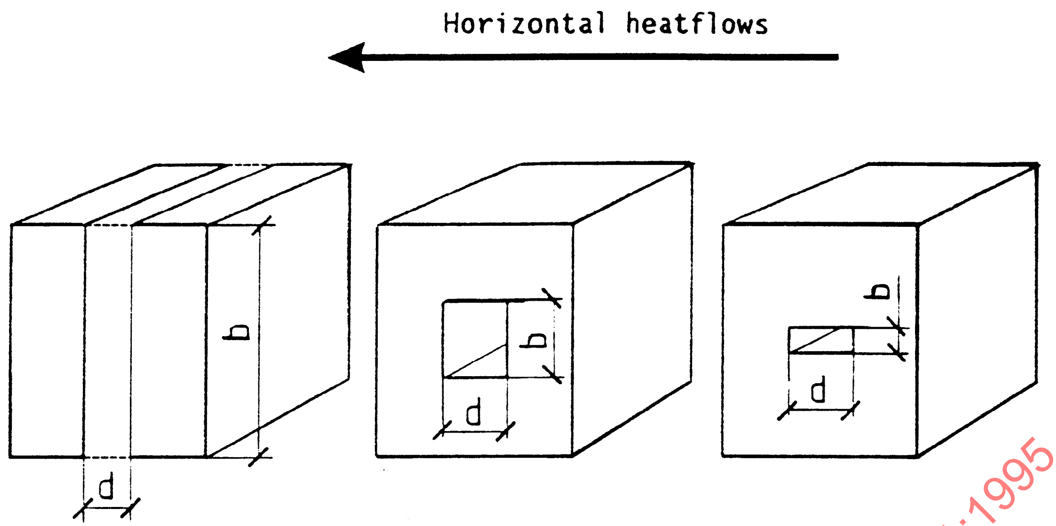


Figure B.1: Section of the air cavity with the heat flow direction

Table B.1: Thermal resistance ($m^2 \cdot K/W$) of air layers and tube-shaped cavities in constructions with $U < 1,0$ W/($m^2 \cdot K$)

d in (mm)	d/b	10	5	3	2	1	0,5	0,3	≤0,1
2		0,07	0,07	0,07	0,07	0,06	0,06	0,06	0,06
5		0,14	0,14	0,13	0,13	0,13	0,12	0,12	0,11
7		0,17	0,17	0,17	0,16	0,15	0,14	0,14	0,13
10		0,21	0,21	0,20	0,20	0,18	0,17	0,16	0,15
15		0,26	0,25	0,24	0,24	0,22	0,20	0,19	0,17
25		0,29	0,28	0,27	0,26	0,24	0,22	0,20	0,18
25 to 500		0,29	0,28	0,27	0,26	0,24	0,22	0,20	0,18

Note: The values are based on a horizontal heat flow direction. For a width d > 500 mm, cavities should be treated as rooms.

B.3 Thermal conductivity of tube-shaped cavities in constructions with a relatively high thermal transmittance

The thermal conductivity of unventilated tube-shaped cavities with a mean thermal transmittance of more than 1,0 W/($m^2 \cdot K$) are given in tables B.2 and B.3.

The dimensions of d and b relative to the heat flow direction are shown in figure B.2.

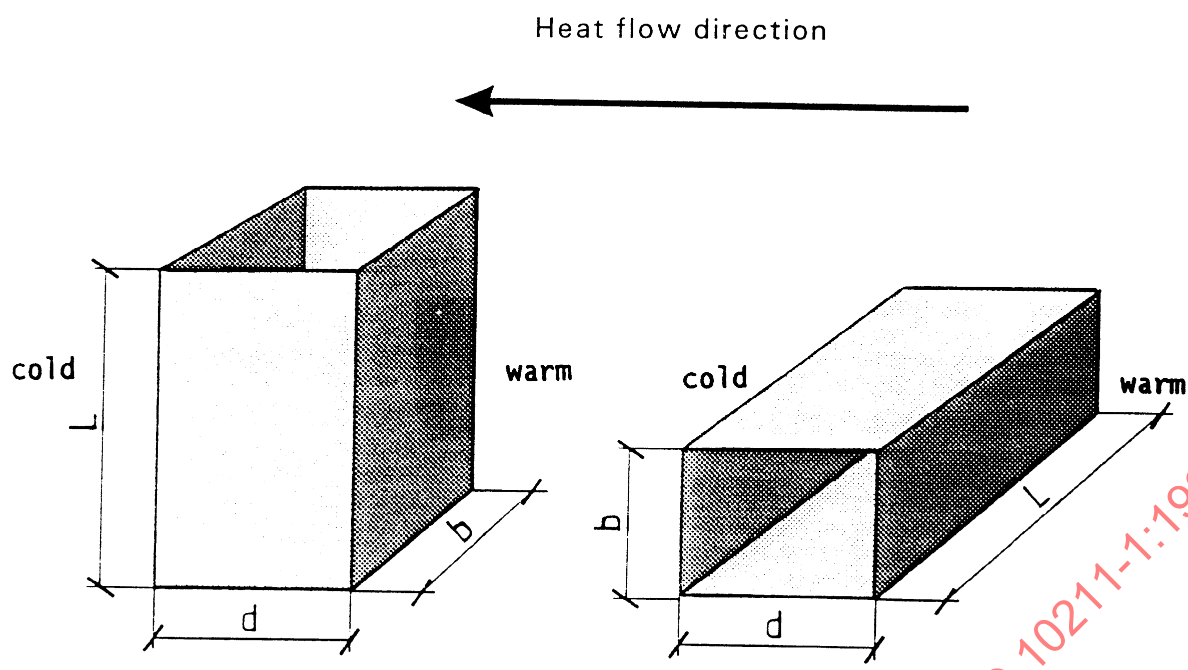


Figure B.2: Section of the tube-shaped air cavity with the heat flow direction. Right: see table B.2, left: see table B.3.

Table B.2: The equivalent thermal conductivity (W/(m·K) of horizontal tube-shaped cavities in constructions with U > 1,0 W/(m²·K)

b (mm)	d (mm)	5	10	20	30	40	50	60	80
5		0,042	0,055	0,079	0,103	0,128	0,152	0,176	0,225
10		0,044	0,066	0,100	0,126	0,151	0,174	0,197	0,243
20		0,046	0,075	0,133	0,181	0,217	0,248	0,277	0,331
30		0,047	0,078	0,138	0,192	0,242	0,290	0,336	0,427
40		0,047	0,079	0,142	0,197	0,249	0,298	0,346	0,437
50		0,047	0,079	0,144	0,202	0,255	0,305	0,354	0,447
60		0,047	0,078	0,146	0,205	0,260	0,312	0,361	0,455
80		0,048	0,076	0,147	0,210	0,267	0,321	0,372	0,470

Table B.3: The equivalent thermal conductivity (W/(m·K) of vertical tube-shaped cavities in constructions with U > 1,0 W/(m²·K)

b (mm)	d (mm)	5	10	20	30	40	50	60	80
5		0,042	0,055	0,085	0,124	0,163	0,202	0,242	0,320
10		0,044	0,059	0,090	0,130	0,169	0,208	0,247	0,326
20		0,046	0,063	0,098	0,139	0,180	0,219	0,259	0,337
30		0,047	0,066	0,104	0,147	0,189	0,229	0,269	0,348
40		0,047	0,067	0,107	0,153	0,196	0,238	0,278	0,358
50		0,047	0,068	0,110	0,157	0,202	0,245	0,286	0,368
60		0,047	0,068	0,112	0,161	0,207	0,251	0,293	0,376
80		0,048	0,069	0,114	0,166	0,214	0,260	0,305	0,391

NOTE: The values of equivalent thermal conductivities given in tables B.2 and B.3 have been calculated numerically for cavities with a rectangular section, an emissivity of the internal surfaces of 0,95 and thermal breaks in the otherwise highly conductive connecting faces. Different values may apply to other geometries. With lower emissivities lower values will be obtained.

Annex C (normative)

Determination of the linear and point thermal transmittances

An alternative expression for the total coupling coefficient $L_{i,j}$ which uses the linear and point thermal transmittances, Ψ and χ, is given by equation (C.1):

$$L_{i,j} = \sum_{n-1}^{N} \chi_{n(i,j)} + \sum_{m-1}^{M} \psi_{m(i,j)} \cdot l_m + \sum_{k-1}^{K} U_{k(i,j)} \cdot A_k \qquad \text{(C.1)}$$

where:

$\chi_{n(i,j)}$ is the point thermal transmittance of part n of the room or building;

$\Psi_{m(i,j)}$ is the linear thermal transmittance of part m of the room or building;

l_m is the length over which the value $\Psi_{m(i,j)}$ applies;

$U_{k(i,j)}$ is the thermal transmittance of part k of the room or building;

A_k is the area over which the value $U_{k(i,j)}$ applies;

N is the number of point thermal transmittances;

M is the number of linear thermal transmittances;

K is the number of thermal transmittances.

NOTE: In formula (C.1) ΣA_p is equal to the total surface area of the envelope.

Ψ values are determined from:

$$\psi = L^{2D} - \sum_{j-1}^{J} U_j \cdot l_j \qquad \text{(C.2)}$$

where:

L^{2D} is the linear thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments being considered;

U_j is the thermal transmittance of the 1-D component j separating the two environments being considered;

l_j is the length over which the value U_j applies.

χ values are determined from:

$$\chi = L^{3D} - \sum_{j=1}^{J} L_j^{2D} \cdot l_j + \sum_{i=1}^{I} U_i \cdot A_i \qquad (C.3)$$

where:

L^{3D} is the thermal coupling coefficient obtained from a 3-D calculation of the 3-D component separating the two environments being considered;

L_j^{2D} is the linear thermal coupling coefficient obtained from a 2-D calculation of the 2-D component j separating the two environments being considered;

l_j is the length over which the value L_j^{2D} applies;

U_i is the thermal transmittance of the 1-D component i separating the two environments being considered;

A_i is the area over which the value U_i applies;

J is the number of 2-D components;

I is the number of 1-D components.

NOTE: When determining Ψ and χ values, it is necessary to state which dimensions (e.g. internal or external) are being used because for several types of thermal bridges the Ψ and χ values depend on this choice.

This annex shows three typical arrangements of building components:

- ***Case 1 with two separate environments***
- ***Case 2 with three separate environments***
- ***Case 3 with five separate environments***

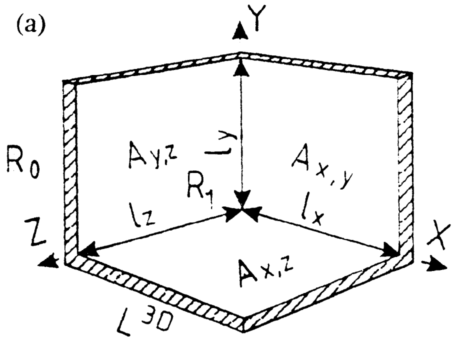
For each case the specific equations to be used in determining Ψ and χ values are given.

Case 1

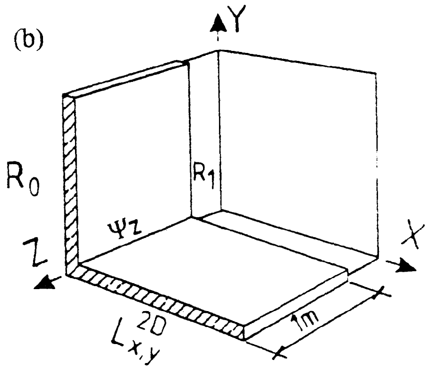
A 3-D building component separating two environments R_1 and R_0.

The following specific equations are used to determine Ψ and χ values

(a)

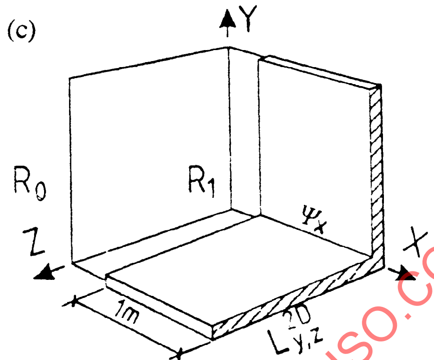


(b)



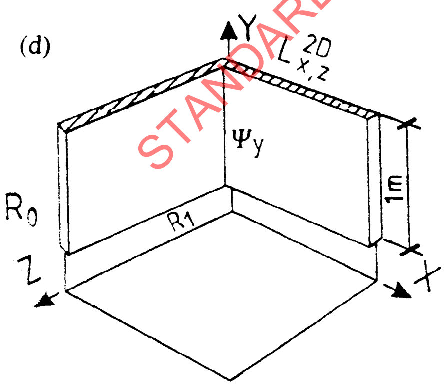
$$\Psi_z = L_{1,0}^{2D(x,y)} - U_{x,z} \cdot l_x - U_{y,z} \cdot l_y$$

(c)



$$\Psi_x = L_{1,0}^{2D(y,z)} - U_{x,y} \cdot l_y - U_{x,z} \cdot l_z$$

(d)



$$\Psi_y = L_{1,0}^{2D(x,z)} - U_{x,y} \cdot l_x - U_{y,z} \cdot l_z$$

$$\chi = L_{1,0}^{3D} - L^{2D(x,y)} \cdot l_z - L_{1,0}^{2D(y,z)} \cdot l_x - L_{1,0}^{2D(x,z)} \cdot l_y + U_{x,y} \cdot A_{x,y} + U_{y,z} \cdot A_{y,z} + U_{x,z} \cdot A_{y,z}$$

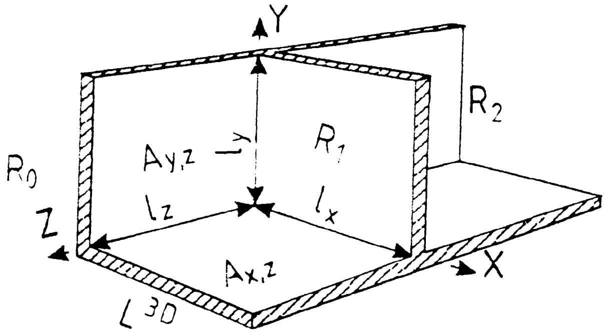
Figure C.1: 3-D building component separating two environments

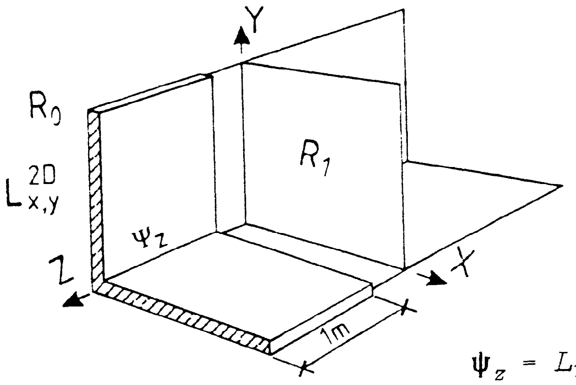
Case 2

A 3-D building component separating three environments.

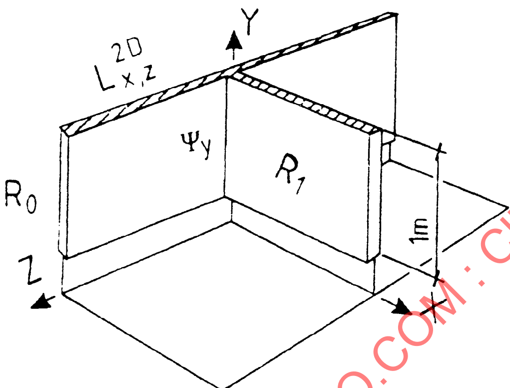
Consider the two environments R_1 and R_0.

The following specific equations are used to determine Ψ and χ values

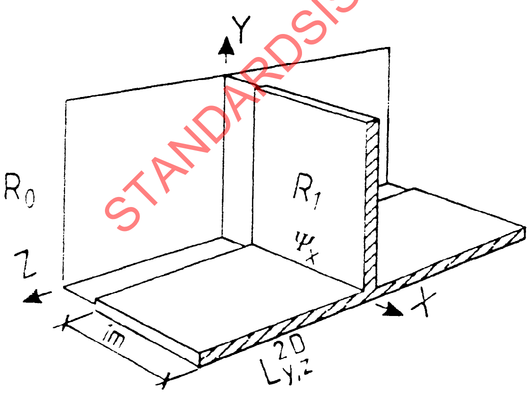




$$\Psi_z = L_{1,0}^{2D(x,y)} - U_{x,z} \cdot l_x - U_{y,z} \cdot l_y$$



$$\Psi_y = L_{1,0}^{2D(x,z)} - U_{y,z} \cdot l_z$$



$$\Psi_x = L_{1,0}^{2D(y,z)} - U_{x,z} \cdot l_z$$

$$\chi = L_{1,0}^{3D} - L_{1,0}^{2D(x,y)} \cdot l_z - L_{1,0}^{2D(y,z)} \cdot l_x - L_{1,0}^{2D(x,z)} \cdot l_y + U_{y,z} \cdot A_{y,z} + U_{x,z} \cdot A_{x,z}$$

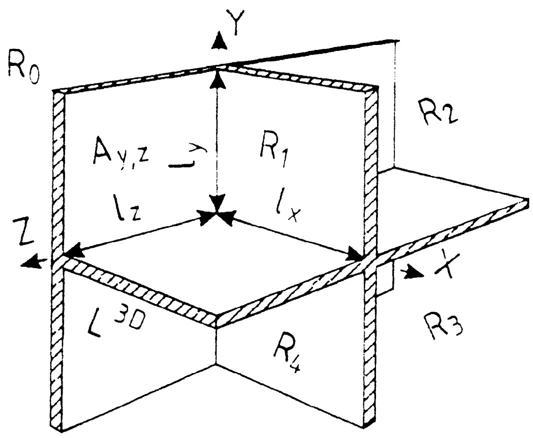
Figure C.2: 3-D building component separating three environments

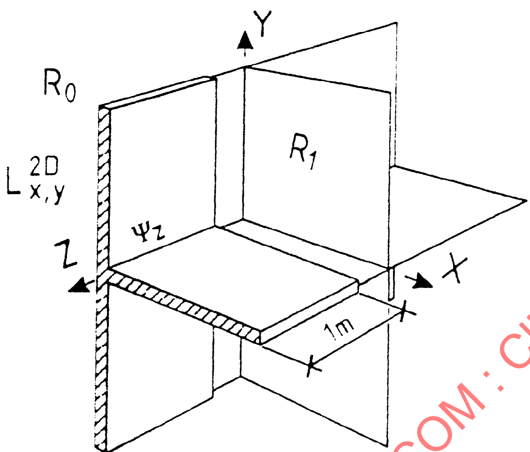
Case 3

A 3-D building component separating five environments.

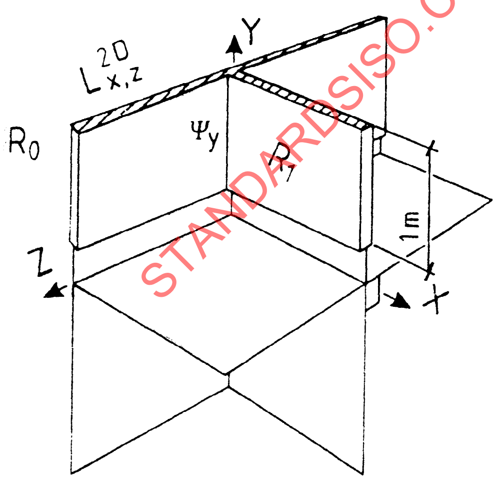
Consider the two environments R_1 and R_0.

The following specific equations are used to determine Ψ and χ values





$$\Psi_z = L_{1,0}^{2D(x,y)} - U_{y,z} \cdot l_y$$



$$\Psi_y = L_{1,0}^{2D(x,z)} - U_{y,z} \cdot l_z$$

$$\chi = L_{1,0}^{3D} - L_{1,0}^{2D(x,y)} \cdot l_z - L_{1,0}^{2D(y,z)} \cdot l_y + U_{y,z} \cdot A_{y,z}$$

Figure C.3: 3-D building component separating five environments

Annex D (informative)

Examples of the use of quasi-homogeneous layers

D.1 Masonry wall with insulated cavity and wall-ties.

Figure D.1 shows a partially insulated cavity wall with 4 wall-ties per square metre. The diameter of the wall-ties is 6 mm.

Six layers (1 to 6) can be identified. For each layer the condition for using a quasi-homogeneous layer is given in table D.1.

Table D.1 also gives the effective thermal conductivity for each quasi-homogeneous layer, calculated with equation (2).

Dimensions in mm

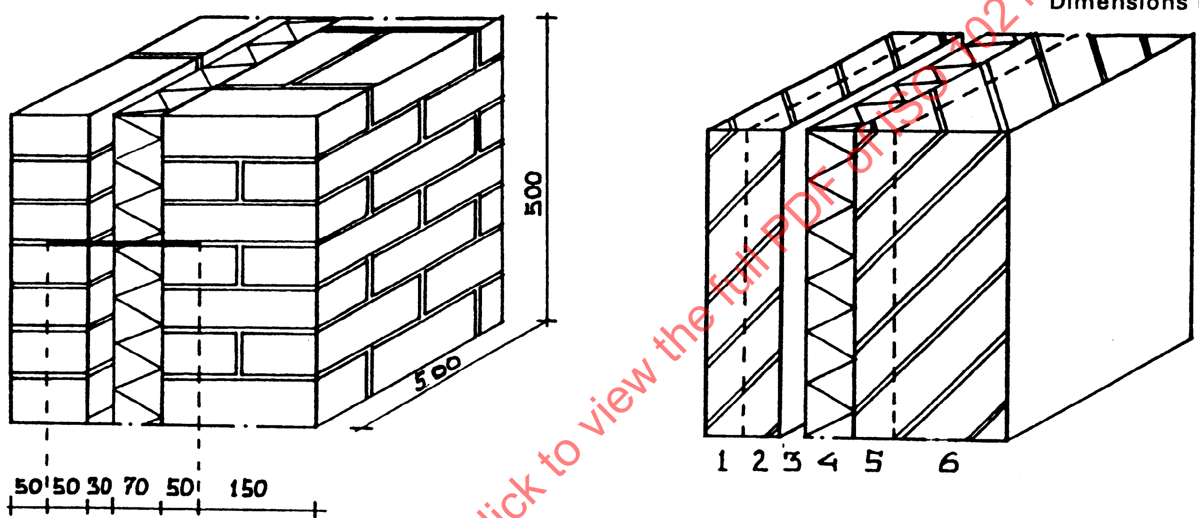


Figure D.1: Simplification of a masonry wall with wall ties

Table D.1: Calculation example for figure D.1

Layer	Material	λ W/(m·K)	A_{tb}/A	Condition:table 3	λ' W/(m·k)
1 external leaf	brick mortar	1,0 1,0	0,85 0,15	-	1,0
2 external leaf	brick mortar wall-tie	1,0 1,0 60	0,85 0,15 0,00011	group 2	1,007
3 cavity	cavity wall-tie	0,167 60	1,00 0,00011	group 2	0,174
4 insulation	insulation wall-tie	0,04 60	1,00 0,00011	group 4	0,047
5 inner leaf	brick mortar wall-tie	0,7 1,0 60	0,85 0,15 0,00011	linear: group 1 point: group 2	0,752
6 inner leaf	brick mortar	0,7 1,0	0,85 0,15	linear: group 1 point: group 2	0,745

The results of table D.1 show that recalculation of the thermal conductivity of the layers 2, 3 and 5 is in fact unnecessary because the effect of the recalculation on the calculated temperature factor is less than 0,005.
The only significant effect on the temperature factor is caused by the wall-tie penetrating the insulation layer.

Unnecessary use of quasi-homogeneous layers can be prevented by a preliminary check.

D.2 Insulated timber frame wall

Figure D.2 shows an insulated timber-frame wall with a frame size of 45 mm x 120 mm each 600 mm. Behind the rendering there is a slightly ventilated cavity. At the internal side a facing on horizontal laths is added. The horizontal laths introduce distributed minor point thermal bridges.Seven layers (1 to 7) can be identified. For layers 2, 4 and 6 the condition for using a quasi-homogeneous layer is given in table D.1.

Table D.2 also gives the effective thermal conductivity for each quasi-homogeneous layer, calculated using equation (2).

Dimensions in mm

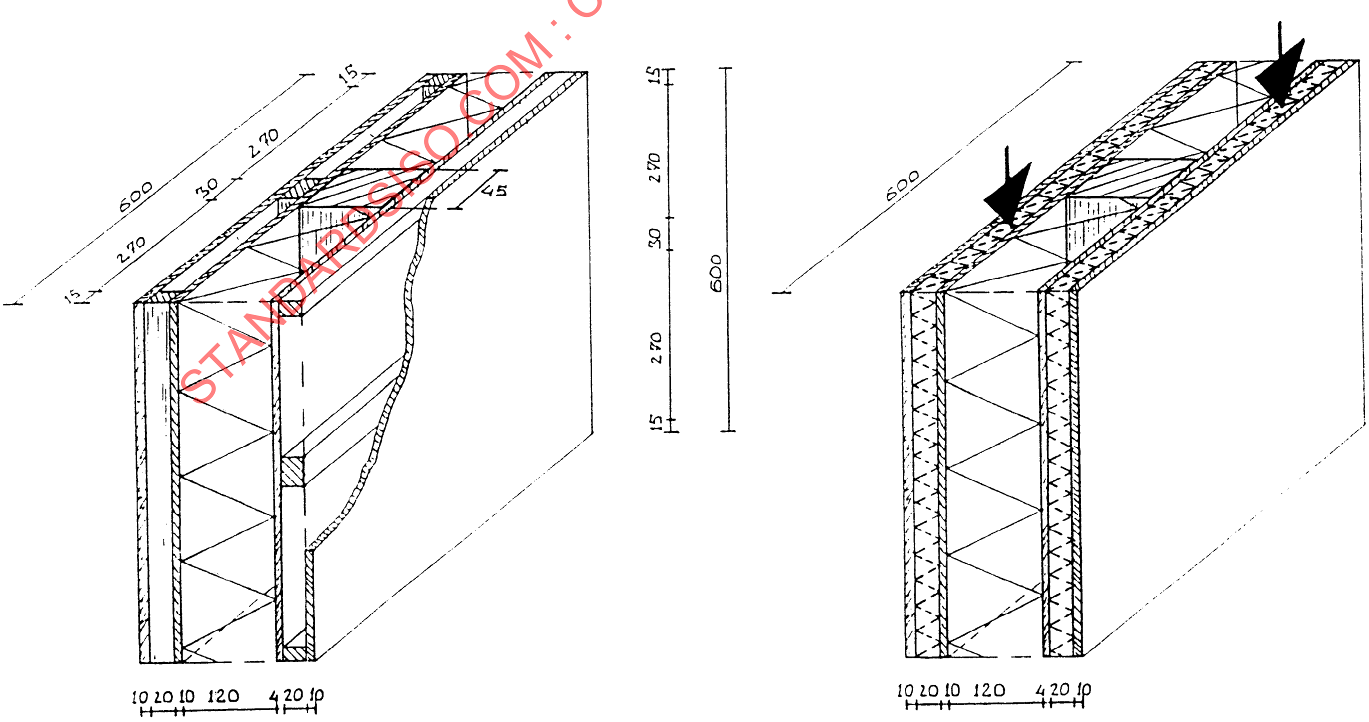


Figure D.2: Simplification of an insulated timber-frame construction with rendering and internal facing

Table D.2: Calculation example for figure D.2

Layer	Material	λ W/(m·K)	A_{tb}/A	condition:table 3	λ' W/(m·K)
1 rendering	wood	0,23	1,0	-	0,23
2 slightly ventilated cavity	cavity laths	0,23 0,14	0,90 0,10	group 1	0,221
3 facing	plywood	0,17	1,00	-	0,17
4 insulation	frame insulation	0,14 0,04	0,05 0,95	not fulfilled	no simplifica tion
5 facing	plywood vapour barrier	0,17 -	1,00	-	0,17
6 unventilated cavity	cavity laths	0,12 0,14	0,90 0,10	group 1	0,122
7 internal facing	gypsum board	0,35	1,00	-	0,35

The results of table D.2 show that recalculation of the thermal conductivity of air layers with limited width, bridged by wooden laths is normally not necessary and the laths can be ignored. The distributed point thermal bridges are eliminated in the geometrical model. Layer 4 does not fulfil the requirements for simplification and the frame should be part of the geometrical model.

The difference between the thermal conductivities of layer 2 and 6 are due to the "slight ventilation" of layer 2, according to EN ISO 6946-1.

Annex E (informative)

Internal surface resistances

E.1 General

The internal surface resistance depends not only on the convective and radiative coefficients but also on the definition of the internal reference temperature and the temperature distribution in the room.

In general the temperature distribution in a room is not uniform. As a consequence the calculation value of R_{si} is not uniform in the room. The correct calculation values of R_{si} can be determined with a thermal model of the room if the following information is available:

a) the thermal resistances of the surrounding planes;
b) the temperatures of the adjacent environments;
c) the distribution of the air temperature in the room;
d) the geometry of the room.

With this information the surface temperature of each surface area can be calculated numerically and hence the values of R_{si} for each area at the internal surface of the envelope can be determined.

If no information on the geometry of the room is available the spatial distribution of the surface temperatures in the room cannot be determined precisely and a simplified method can be used, which assumes the room to have a uniform surface temperature determined by the mean thermal transmittance of the room. This simplification gives an adequate approximation of the more elaborate numerical calculation based on a specific room geometry.

E.2 Simplified calculation of the surface resistance

For this simplified calculation the internal surface resistance is given by:

$$R_{si} = \frac{(1 + p\,R_{eq})}{(h_c + h_r - p)} \qquad \text{(E.1)}$$

with the "room parameter" p:

$$p = \frac{\{h_c(\theta_{ref} - \theta_{ay}) + h_r(\theta_{ref} - \theta_r)\}}{(\theta_{ref} - \theta_e)} \qquad \text{(E.2)}$$