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Thermal performance of buildings — Heat transfer via the ground — Calculation methods

Performance thermique des bâtiments — Transfert de chaleur par le sol — Méthodes de calcul

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Foreword

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

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

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

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

ISO 13370 was prepared by Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*.

This second edition cancels and replaces the first edition (ISO 13370:1998), which has been technically revised.

The following principal changes have been made to the first edition:

- Clause 4 contains a revised text to clarify the intention of the initial part of the former Annex A; the rest of the former Annex A is now contained in ISO 10211;
- 7.2 no longer contains a table of linear thermal transmittances: it is now recognized, as with other thermal bridging, that the wall/floor junction often needs to be calculated;
- 9.1 provides an alternative formula for well-insulated floors;
- 9.2 provides clarification for low-emissivity surfaces;
- Annex A contains formulae for cooling applications;
- Annex B has incorporated minor revisions to the text for edge-insulated floors;
- Annex D has been revised;
- Annex F (formerly Annex C) has been changed to informative status.

Introduction

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

In contrast with ISO 6946, which gives the method of calculation of the thermal transmittance of building elements in contact with the external air, this International Standard deals with elements in thermal contact with the ground. The division between these two International Standards is at the level of the inside floor surface for slab-on-ground floors, suspended floors and unheated basements, and at the level of the external ground surface for heated basements. In general, a term to allow for a thermal bridge associated with the wall/floor junction is included when assessing the total heat loss from a building using methods such as ISO 13789.

The calculation of heat transfer through the ground can be done by numerical calculations, which also allow analysis of thermal bridges, including wall/floor junctions, for assessment of minimum internal surface temperatures.

In this International Standard, methods are provided which take account of the three-dimensional nature of the heat flow in the ground below buildings.

Thermal transmittances of floors give useful comparative values of the insulation properties of different floor constructions, and are used in building regulations in some countries for the limitation of heat losses through floors.

Thermal transmittance, although defined for steady-state conditions, also relates average heat flow to average temperature difference. In the case of walls and roofs exposed to the external air, there are daily periodic variations in heat flow into and out of storage related to daily temperature variations, but this averages out, and the daily average heat loss can be found from the thermal transmittance and daily average inside-to-outside temperature difference. For floors and basement walls in contact with the ground, however, the large thermal inertia of the ground results in periodic heat flows related to the annual cycle of internal and external temperatures. The steady-state heat flow is often a good approximation to the average heat flow over the heating season.

In addition to the steady-state part, a detailed assessment of floor losses is obtained from annual periodic heat transfer coefficients related to the thermal capacity of the soil, as well as its thermal conductivity, together with the amplitude of annual variations in monthly mean temperature.

Annex D provides a method for incorporating heat transfers to and from the ground into calculations undertaken at short time steps (e.g. one hour).

Worked examples illustrating the use of the methods in this International Standard are given in Annex K.

Thermal performance of buildings — Heat transfer via the ground — Calculation methods

1 Scope

This International Standard provides methods of calculation of heat transfer coefficients and heat flow rates for building elements in thermal contact with the ground, including slab-on-ground floors, suspended floors and basements. It applies to building elements, or parts of them, below a horizontal plane in the bounding walls of the building situated

- for slab-on-ground floors, suspended floors and unheated basements, at the level of the inside floor surface;

  NOTE In some cases, external dimension systems define the boundary at the lower surface of the floor slab.

- for heated basements, at the level of the external ground surface.

This International Standard includes calculation of the steady-state part of the heat transfer (the annual average rate of heat flow) and the part due to annual periodic variations in temperature (the seasonal variations of the heat flow rate about the annual average). These seasonal variations are obtained on a monthly basis and, except for the application to dynamic simulation programmes in Annex D, this International Standard does not apply to shorter periods of time.

2 Normative references

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

ISO 6946, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation method*

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

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

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

ISO 14683, *Thermal bridges in building construction — Linear thermal transmittance — Simplified methods and default values*

3 Terms, definitions, symbols and units

3.1 Terms and definitions

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

3.1.1
slab on ground
floor construction directly on the ground over its whole area

3.1.2
suspended floor
floor construction in which the lowest floor is held off the ground, resulting in an air void between the floor and the ground

NOTE This air void, also called underfloor space or crawl space, may be ventilated or unventilated, and does not form part of the habitable space.

3.1.3
basement
usable part of a building that is situated partly or entirely below ground level

NOTE This space may be heated or unheated.

3.1.4
equivalent thickness
〈thermal resistance〉 thickness of ground (having the thermal conductivity of the actual ground) which has the same thermal resistance as the element under consideration

3.1.5
steady-state heat transfer coefficient
steady-state heat flow divided by temperature difference between internal and external environments

3.1.6
internal periodic heat transfer coefficient
amplitude of periodic heat flow divided by amplitude of internal temperature variation over an annual cycle

3.1.7
external periodic heat transfer coefficient
amplitude of periodic heat flow divided by amplitude of external temperature over an annual cycle

3.1.8
characteristic dimension of floor
area of floor divided by half the perimeter of floor

3.1.9
phase difference
period of time between the maximum or minimum of a cyclic temperature and the consequential maximum or minimum heat flow rate

3.2 Symbols and units

The following is a list of the principal symbols used. Other symbols are defined where they are used within the text.

Symbol	Quantity	Unit
A	area of floor	m^2
B'	characteristic dimension of floor	m
c	specific heat capacity of unfrozen ground	J/(kg·K)
d_g	total equivalent thickness – ground below suspended floor	m
d_t	total equivalent thickness – slab-on-ground floor	m
d_w	total equivalent thickness – basement wall	m
H_g	steady-state ground heat transfer coefficient	W/K
h	height of floor surface above outside ground level	m
P	exposed perimeter of floor	m
Q	quantity of heat	J
R	thermal resistance	$m^2·K/W$
R_f	thermal resistance of floor construction	$m^2·K/W$
R_{si}	internal surface resistance	$m^2·K/W$
R_{se}	external surface resistance	$m^2·K/W$
U	thermal transmittance between internal and external environments	$W/(m^2·K)$
U_{bf}	thermal transmittance of basement floor	$W/(m^2·K)$
U_{bw}	thermal transmittance of basement walls	$W/(m^2·K)$
U'	effective thermal transmittance for whole basement	$W/(m^2·K)$
w	thickness of external walls	m
z	depth of basement floor below ground level	m
Φ	heat flow rate	W
λ	thermal conductivity of unfrozen ground	W/(m·K)
ρ	density of unfrozen ground	kg/m^3
θ	temperature	°C
Ψ_g	linear thermal transmittance associated with wall/floor junction	W/(m·K)
$\Psi_{g,e}$	linear thermal transmittance associated with edge insulation	W/(m·K)

4 Methods of calculation

Heat transfer via the ground is characterized by:

- heat flow related to the area of the floor, depending on the construction of the floor;
- heat flow related to the perimeter of the floor, depending on thermal bridging at the edge of the floor;
- annual periodic heat flow, also related to the perimeter of the floor, resulting from the thermal inertia of the ground.

The steady-state, or annual average, part of the heat transfer shall be evaluated using one of the methods described below.

a) A full three-dimensional numerical calculation, giving the result directly for the floor concerned: calculations shall be done in accordance with ISO 10211. The result is applicable only for the actual floor dimensions modelled.

b) A two-dimensional numerical calculation, using a floor that is infinitely long and has a width equal to the characteristic dimension of the floor (floor area divided by half perimeter, see 8.1): calculations shall be done in accordance with ISO 10211. The result is applicable to floors having the characteristic dimension that was modelled.

NOTE The largest heat flows usually occur near the edges of the floor, and in most cases only small errors result from converting the three-dimensional problem to a two-dimensional problem in which the width of the building is taken as the characteristic dimension of the floor.

c) The area-related heat transfer calculated by the formulae given in this International Standard (see Clause 9), together with the edge-related heat transfer obtained from a two-dimensional numerical calculation in accordance with ISO 10211.

d) The area-related heat transfer calculated by the formulae given in this International Standard (see Clause 9), together with the edge-related coefficients obtained from, for example, tables prepared in accordance with ISO 14683.

For c) and d), the steady-state part of the heat transfer is given by Equation (1):

$$H_\mathrm{g} = AU + P\Psi_\mathrm{g} \tag{1}$$

where Ψ_g is obtained by numerical calculation in method c), or from a table of values in method d).

In both cases, the method is applicable to a floor of any size or shape. U depends on floor size, but Ψ_g is independent of the floor dimensions. Equation (1) is modified in the case of a heated basement (see 9.3.4) and in the case of application of Annex B (see B.1).

For annual periodic heat flow, see 7.3 and Annex A.

5 Thermal properties

5.1 Thermal properties of the ground

The thermal properties of the ground may be specified in national regulations or other documents, and such values may be used where appropriate. In other cases, the following apply:

a) if known, use values for the actual location, averaged over a depth equal to the width of the building and allowing for the normal moisture content;

b) if the soil type is known or specified, use the values in Table 1;

c) otherwise, use $\lambda = 2{,}0$ W/(m·K) and $\rho c = 2{,}0 \times 10^6$ J/(m^3·K).

NOTE Annex G gives information about the range of values of ground properties.

Table 1 — Thermal properties of the ground

Category	Description	Thermal conductivity λ W/(m·K)	Heat capacity per volume ρc J/(m³·K)
1	clay or silt	1,5	$3{,}0 \times 10^6$
2	sand or gravel	2,0	$2{,}0 \times 10^6$
3	homogeneous rock	3,5	$2{,}0 \times 10^6$

5.2 Thermal properties of building materials

For the thermal resistance of any building product, use the appropriate design value as defined in ISO 10456. The thermal resistance of products used below ground level should reflect the moisture and temperature conditions of the application.

If thermal conductivity is quoted, obtain the thermal resistance as the thickness divided by thermal conductivity.

NOTE The heat capacity of building materials used in floor constructions is small compared with that of the ground, and is neglected.

5.3 Surface resistances

Values of surface resistance shall conform to ISO 6946.

R_{si} applies both at the top and the bottom of an underfloor space.

6 Internal temperature and climatic data

6.1 Internal temperature

If there are different temperatures in different rooms or spaces immediately above the floor, a spatial average should be used. Obtain this average by weighting the temperature of each space by the area of that space in contact with the ground.

To calculate heat flow rates, this International Standard requires:

a) annual mean internal temperature;

b) if variations in internal temperature are to be included, amplitude of variation of internal temperature from the annual mean; this amplitude is defined as half the difference between the maximum and minimum values of the average temperatures for each month.

6.2 Climatic data

To calculate heat flow rates, this International Standard requires:

a) annual mean external air temperature;

b) if variations in external temperature are to be included, amplitude of variation of external air temperature from the annual mean; this amplitude is defined as half the difference between the maximum and minimum values of the average temperatures for each month;

c) for suspended floors that are naturally ventilated, the average wind speed measured at a height of 10 m above external ground level.

If the ground surface temperature is known or can be estimated, this can be used in place of the external air temperature, in order to allow for effects of snow cover, solar gain on the ground surface and/or longwave radiation to clear skies. In such cases, R_{se} should be excluded from all formulae.

7 Thermal transmittance and heat flow rate

7.1 Thermal transmittance

Thermal transmittances for floors and basements are related to the steady-state component of the heat transfer. Methods of calculation are given in Clause 9 for the various types of floor and basement. The formulae use the characteristic dimension of the floor and the equivalent thickness of floor insulation (see Clause 8).

If the transmission heat loss coefficient for the ground is required, take this as equal to the steady-state ground heat transfer coefficient, H_g, calculated using Equation (1).

7.2 Thermal bridges at edge of floor

The formulae in this International Standard are based on an isolated floor considered independently of any interaction between floor and wall. They also assume uniform thermal properties of the soil (except for effects solely due to edge insulation).

In practice, wall/floor junctions for slab-on-ground floors do not correspond with this ideal, giving rise to thermal bridge effects. These shall be allowed for in calculations of the total heat loss from a building, by using a linear thermal transmittance, Ψ_g.

NOTE The linear thermal transmittance depends on the system being used for defining building dimensions (see ISO 13789).

The total heat loss from a building is then calculated on the basis of a separating plane

- at the level of the inside floor surface for slab-on-ground floors, suspended floors and unheated basements, or
- at the level of the outside ground surface for heated basements.

NOTE In some cases, external dimension systems define the boundary at the lower surface of the floor slab.

The thermal transmittance of elements above the separating plane should be assessed in accordance with appropriate standards, such as ISO 6946.

7.3 Calculation of heat flow rate

Heat transfer via the ground can be calculated on an annual basis using only the steady-state ground heat transfer coefficient, or on a seasonal or monthly basis using additional periodic coefficients that take account of the thermal inertia of the ground. The relevant equations are given in Annex A.

7.4 Effect of ground water

Ground water has a negligible effect on the heat transfer, unless it is at a shallow depth and has a high flow rate. Such conditions are rarely encountered and in most cases no allowance should be made for the effect of ground water.

When the depth of the water table below ground level and the rate of ground water flow are known, the steady-state ground heat transfer coefficient, H_g, may be multiplied by a factor, G_w.

NOTE Illustrative values of G_w are given in Annex H.

7.5 Special cases

The methods in this International Standard are also applicable to the following situations, with the modifications described in the relevant annex:

- heat flow rates for individual rooms (see Annex C);
- application to dynamic simulation programmes (see Annex D).

NOTE This International Standard can also be used for slab-on-ground floors with an embedded heating system (see Annex I) and for cold stores (see Annex J).

8 Parameters used in the calculations

8.1 Characteristic dimension of floor

To allow for the three-dimensional nature of heat flow within the ground, the formulae in this International Standard are expressed in terms of the “characteristic dimension” of the floor, B', defined as the area of the floor divided by half the perimeter:

$$B' = \frac{A}{0{,}5\,P} \tag{2}$$

NOTE For an infinitely long floor, B' is the width of the floor; for a square floor, B' is half the length of one side.

Special foundation details, e.g. edge insulation of the floor, are treated as modifying the heat flow at the perimeter.

In the case of basements, B' is calculated from the area and perimeter of the floor of the basement, not including the walls of the basement, and the heat flow from the basement includes an additional term related to the perimeter and the depth of the basement floor below ground level.

In this International Standard, P is the exposed perimeter of the floor: the total length of external wall dividing the heated building from the external environment or from an unheated space outside the insulated fabric. Therefore,

- for a complete building, P is the total perimeter of the building and A is its total ground-floor area;
- to calculate the heat loss from part of a building (e.g. for each individual dwelling in a row of terraced houses), P includes the lengths of external walls separating the heated space from the external environment and excludes the lengths of walls separating the part under consideration from other heated parts of the building, while A is the ground-floor area under consideration;
- unheated spaces outside the insulated fabric of the building (such as porches, attached garages or storage areas) are excluded when determining P and A (but the length of the wall between the heated building and the unheated space is included in the perimeter; the ground heat losses are assessed as if the unheated spaces were not present).

8.2 Equivalent thickness

The concept of "equivalent thickness" is introduced to simplify the expression of the thermal transmittances.

A thermal resistance is represented by its equivalent thickness, which is the thickness of ground that has the same thermal resistance. In this International Standard:

- d_t is the equivalent thickness for floors;
- d_w is the equivalent thickness for walls of basements below ground level.

The steady-state ground heat transfer coefficients are related to the ratio of equivalent thickness to characteristic floor dimension, and the periodic heat transfer coefficients are related to the ratio of equivalent thickness to periodic penetration depth.

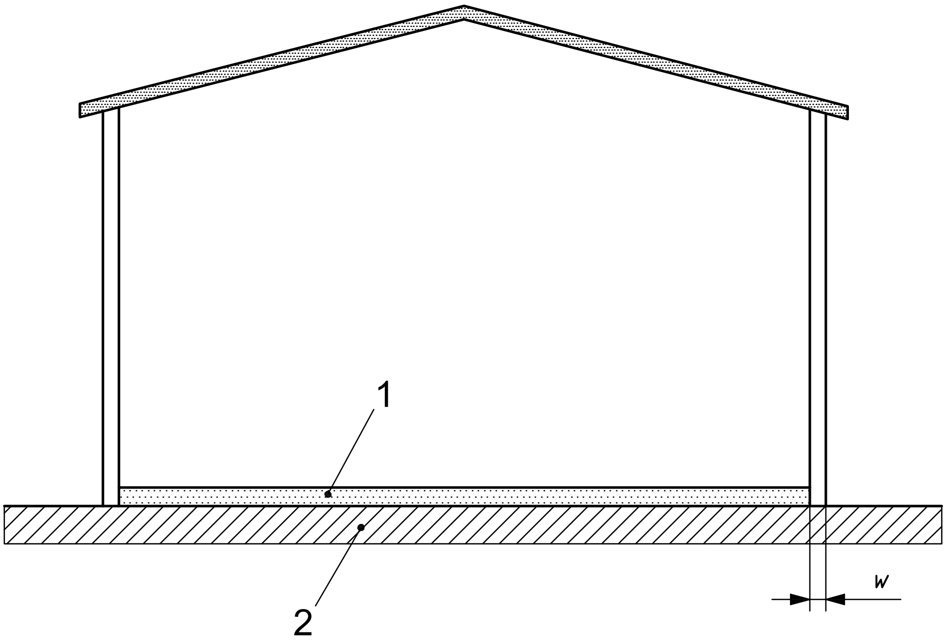
9 Calculation of thermal transmittances

9.1 Slab-on-ground floor

Slab-on-ground floors include any floor consisting of a slab in contact with the ground over its whole area, whether or not supported by the ground over its whole area, and situated at or near the level of the external ground surface (see Figure 1). This floor slab may be

- uninsulated, or
- evenly insulated (above, below or within the slab) over its whole area.

If the floor has horizontal and/or vertical edge insulation, the thermal transmittance can be corrected using the procedure in Annex B.



Key

1 floor slab
2 ground

w thickness of external walls

Figure 1 — Schematic diagram of slab-on-ground floor

The thermal transmittance depends on the characteristic dimension of the floor, B' [see 8.1 and Equation (2)], and the total equivalent thickness, d_t (see 8.2), defined by Equation (3):

$$d_t = w + \lambda\left(R_{si} + R_f + R_{se}\right) \tag{3}$$

where

w is the full thickness of the walls, including all layers;

R_f is the thermal resistance of the floor slab, including that of any all-over insulation layers above, below or within the floor slab, and that of any floor covering;

and the other symbols are defined in 3.2.

The thermal resistance of dense concrete slabs and thin floor coverings may be neglected. Hardcore below the slab is assumed to have the same thermal conductivity as the ground, and its thermal resistance should not be included.

Calculate the thermal transmittance using either Equation (4) or (5), depending on the thermal insulation of the floor.

If $d_t < B'$ (uninsulated and moderately insulated floors),

$$U = \frac{2\lambda}{\pi B' + d_t} \ln\left(\frac{\pi B'}{d_t} + 1\right) \tag{4}$$

If $d_t \geqslant B'$ (well-insulated floors),

$$U = \frac{\lambda}{0{,}457 \times B' + d_t} \tag{5}$$

NOTE 1 For well-insulated floors, it can be written alternatively as

$$U_g = \frac{1}{(R_f + R_{si} + R_{se} + w/\lambda) + R_g}$$

where R_g is the effective thermal resistance of the ground given by

$$R_g = \frac{0{,}457 \times B'}{\lambda}$$

The thermal transmittance shall be rounded to two significant figures if presented as the final result. Intermediate calculations shall be undertaken with at least three significant figures.

NOTE 2 The thermal transmittance can be small for large floors, so that more decimal places are needed.

The steady-state ground heat transfer coefficient between internal and external environments is obtained using Equation (1).

9.2 Suspended floor

A suspended floor is any type of floor held off the ground, e.g. timber or beam-and-block (see Figure 2). This clause deals with the conventional design of suspended floor in which the underfloor space is naturally ventilated with external air. For mechanical ventilation of the underfloor space, or if the ventilation rate is specified, see Annex E.

The thermal transmittance is given by Equation (6):

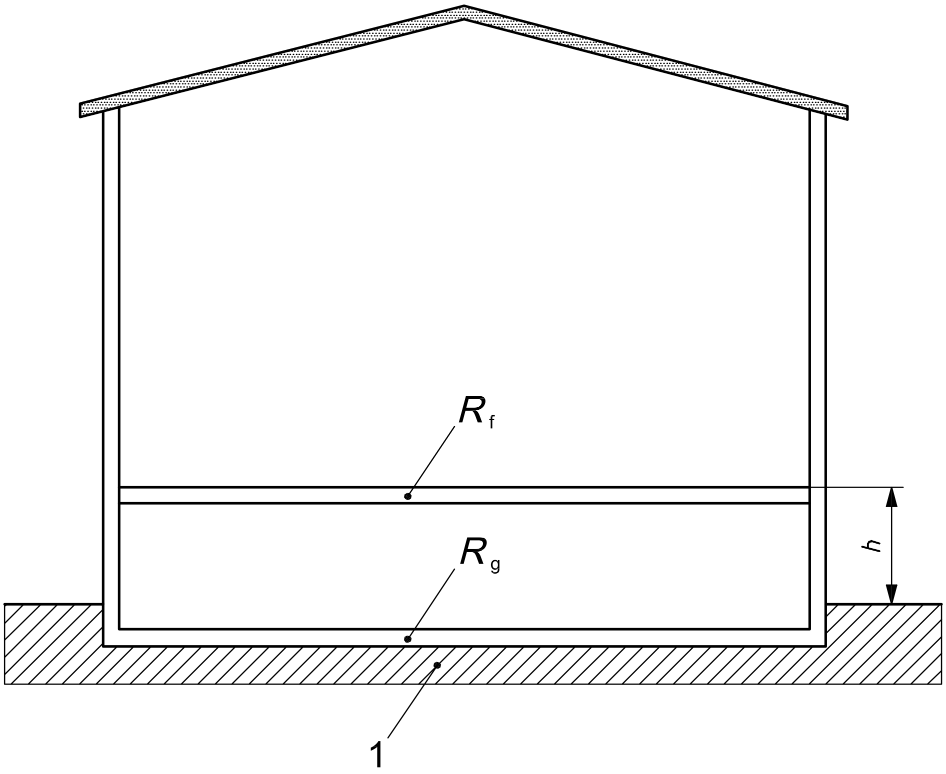
$$\frac{1}{U}=\frac{1}{U_\mathrm{f}}+\frac{1}{U_\mathrm{g}+U_\mathrm{x}} \tag{6}$$

where

U_f is the thermal transmittance of suspended part of floor, in W/(m^2·K) (between the internal environment and the underfloor space);

$U_\mathrm{g}=\frac{1}{R_\mathrm{g}}$ is the thermal transmittance for heat flow through the ground, in W/(m^2·K);

U_x is an equivalent thermal transmittance between the underfloor space and the outside accounting for heat flow through the walls of the underfloor space and by ventilation of the underfloor space, in W/(m^2·K).



Key

1 floor slab

h height of floor surface above outside ground level

R_f thermal resistance of floor construction

R_g effective thermal resistance of ground

Figure 2 — Schematic diagram of suspended floor

The calculation of U_f shall include the effect of any thermal bridging. It may be calculated in accordance with ISO 6946 or by a numerical method. In the case of a low-emissivity surface on the lower side of the floor, the surface resistance may be modified using the procedure given in ISO 6946. Surface resistances for downwards heat flow apply in the case of a heated building, and surface resistances for upwards heat flow apply in the case of a cooled building.

Calculate U_g by means of Equations (2), (7) and (8):

$$d_g = w + \lambda\left(R_{si} + R_f + R_{se}\right) \tag{7}$$

$$U_g = \frac{2\lambda}{\pi B' + d_g} \ln\left(\frac{\pi B'}{d_g} + 1\right) \tag{8}$$

where R_g is the thermal resistance of any insulation on the base of the underfloor space, in m^2·K/W.

If the underfloor space extends to an average depth of more than 0,5 m below ground level, U_g should be calculated according to Equation (E.2).

If edge insulation is applied around the base of the underfloor space, U_g should be modified according to Equation (B.3).

Obtain U_x from Equation (9):

$$U_x = 2 \times \frac{hU_w}{B'} + 1\,450 \times \frac{\varepsilon v f_w}{B'} \tag{9}$$

where

h is the height of the upper surface of the floor above external ground level, in m;

U_w is the thermal transmittance of walls of underfloor space above ground level, in W/(m^2·K), calculated in accordance with ISO 6946;

ε is the area of ventilation openings per perimeter length of underfloor space, in m^2/m;

v is the average wind speed at 10 m height, in m/s;

f_w is the wind shielding factor.

If h varies round the perimeter of the floor, its average value should be used in Equation (9).

Annex E gives equations for the calculation of the average temperature in the underfloor space.

The wind shielding factor relates the wind speed at 10 m height (assumed unobstructed) to that near ground level, allowing for the shielding by adjacent buildings, etc. Representative values are given in Table 2.

Table 2 — Values of the wind shielding factor

Location	Example	Wind shielding factor f_w
Sheltered	City centre	0,02
Average	Suburban	0,05
Exposed	Rural	0,10

The steady-state ground heat transfer coefficient between internal and external environments is obtained using Equation (1).

9.3 Heated basement

9.3.1 General

The procedures given for basements apply to buildings in which part of the habitable space is below ground level (see Figure 3). The basis is similar to that for the slab-on-ground, but allowing for:

- the depth, z, of the floor of the basement below ground level;
- the possibility of different insulation levels being applied to the walls of the basement and to the floor of the basement.

If z varies round the perimeter of the building, its mean value should be used in the calculations.

NOTE 1 If $z = 0$, the formulae reduce to those given in 9.1 for the slab-on-ground.

This International Standard does not directly cover the case of a building having partly a floor on the ground and partly a basement. However, an approximation to the total heat loss via the ground from such a building can be obtained by treating the building as if it had a basement over its whole area with depth equal to half the actual depth of the basement part.

NOTE 2 Basements that are partly heated are treated in 9.5.

The procedures described give the total heat flow from the basement via the ground, i.e. through the floor of the basement and through the walls of the basement below ground level.

NOTE 3 The parts of the walls above ground level can be assessed by their thermal transmittance calculated in accordance with ISO 6946.

9.3.2 Basement floor

To determine U_{bf}, calculate the characteristic dimension for the basement floor using Equation (3), and include any insulation of the basement floor in the total equivalent thickness, d_{t}, given by Equation (10):

$$d_{\mathrm{t}} = w + \lambda \left(R_{\mathrm{si}} + R_{\mathrm{f}} + R_{\mathrm{se}} \right) \tag{10}$$

where

w is the full thickness of the walls of the building at ground level, including all layers;

R_{f} is the thermal resistance of the floor slab, including that of any all-over insulation layers above, below or within the floor slab, and that of any floor covering;

and the other symbols are defined in 3.2.

The thermal resistance of dense concrete slabs and thin floor coverings may be neglected. Hardcore below the slab is assumed to have the same thermal conductivity as the ground and its thermal resistance should be neglected.

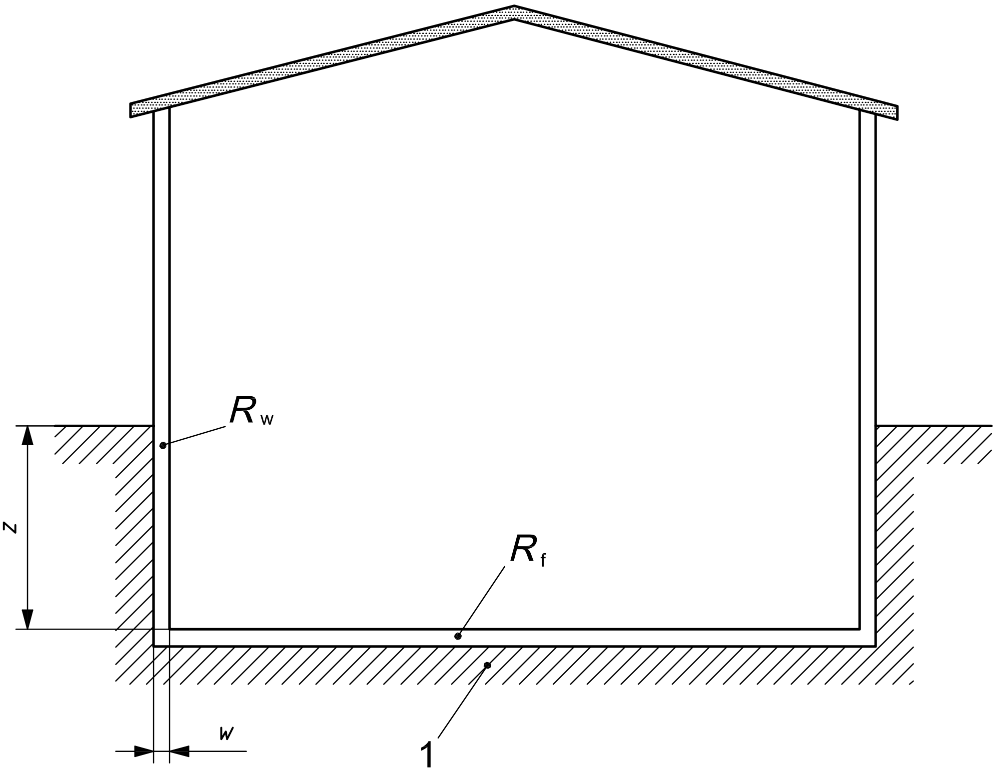
Use either Equation (11) or Equation (12), depending on the thermal insulation of the basement floor.

If $\left(d_{\mathrm{t}} + 0{,}5z \right) < B'$ (uninsulated and moderately insulated basement floors),

$$U_{\mathrm{bf}} = \frac{2\lambda}{\pi B' + d_{\mathrm{t}} + 0{,}5z} \ln \left(\frac{\pi B'}{d_{\mathrm{t}} + 0{,}5z} + 1 \right) \tag{11}$$

If $\left(d_{\mathrm{t}} + 0{,}5z \right) \geqslant B'$ (well-insulated basement floors),

$$U_{\mathrm{bf}} = \frac{\lambda}{0{,}457 B' + d_t + 0{,}5z} \tag{12}$$



Key

1 floor slab

R_f thermal resistance of floor construction

R_w thermal resistance of walls of the basement, including all layers

w thickness of external walls

z depth of basement floor below ground level

Figure 3 — Schematic diagram of building with heated basement

9.3.3 Basement walls

U_{bw} depends on total equivalent thickness for the basement walls, d_w, given by Equation (13):

$$d_w = \lambda \left(R_{si} + R_w + R_{se} \right) \tag{13}$$

where R_w is the thermal resistance of the walls of the basement, including all layers, and the other symbols are defined in 3.2.

Obtain U_{bw} from Equation (14):

$$U_{bw} = \frac{2\lambda}{\pi z}\left(1 + \frac{0,5 d_t}{d_t + z}\right) \ln\left(\frac{z}{d_w} + 1\right) \tag{14}$$

The formula for U_{bw} involves both d_w and d_t. It is valid for $d_w \geqslant d_t$, which is usually the case. If, however, $d_w < d_t$ then d_t should be replaced by d_w in Equation (14).

9.3.4 Heat transfer from whole basement

The effective thermal transmittance characterizing the whole of the basement in contact with the ground is:

$$U' = \frac{\left(AU_{\mathrm{bf}}\right) + \left(zPU_{\mathrm{bw}}\right)}{A + \left(zP\right)} \tag{15}$$

The steady-state ground heat transfer coefficient between internal and external environments is given by Equation (16) (see also Clause 4):

$$H_{\mathrm{g}} = \left(AU_{\mathrm{bf}}\right) + \left(zPU_{\mathrm{bw}}\right) + \left(P\Psi_{\mathrm{g}}\right) \tag{16}$$

NOTE Equation (16) gives the heat flow from the whole basement. The heat transfers through the floor and walls of the basement are interlinked, and for this reason the first two terms in Equation (16), for the heat flow through the floor and walls respectively, are approximations.

9.4 Unheated basement

The formulae given in this subclause apply to unheated basements ventilated from the outside.

The thermal transmittance between internal and external environments, U, is given by Equation (17):

$$\frac{1}{U} = \frac{1}{U_{\mathrm{f}}} + \frac{A}{\left(AU_{\mathrm{bf}}\right) + \left(zPU_{\mathrm{bw}}\right) + \left(hPU_{\mathrm{w}}\right) + \left(0{,}33 \times nV\right)} \tag{17}$$

where

U_{f} is the thermal transmittance of the floor (between the internal environment and the basement);

U_{w} is the thermal transmittance of the walls of the basement above ground level;

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

V is the air volume of the basement.

In the absence of specific information, a value of $n = 0{,}3$ air changes per hour may be used.

Calculate U_{f} and U_{w} in accordance with ISO 6946, using surface resistance values as specified in 5.3.

Calculate U_{bf} and U_{bw} in accordance with 9.3.

NOTE The average temperature in the basement can be calculated by the method in Annex E.

The steady-state ground heat transfer coefficient between internal and external environments is obtained using Equation (1).

9.5 Partly heated basement

The heat flow rates for partly heated basements may be calculated by the following procedure:

a) calculate the heat flow rate for a fully heated basement;

b) calculate the heat flow rate for an unheated basement;

c) combine the heat flow rates in a) and b) in proportion to the areas of heated and unheated parts of the basement in contact with the ground in order to obtain the heat flow rate for a partly heated basement.

Annex A
(normative)

Calculation of ground heat flow rate

A.1 Methods of calculation

Three methods of calculating the heat flow rate, Φ, are provided, as listed below. The user chooses the appropriate method with regard to the purpose of the calculation and the accuracy to which it is necessary or appropriate to evaluate the heat flow rate:

a) calculation of the ground heat flow rate separately for each month (see A.2);

b) calculation of the average ground heat flow rate during the heating season (see A.4);

c) calculation of the annual average ground heat flow rate (see A.5).

A.2 Monthly heat flow rate using sinusoidal temperature variations

To allow for the effect of the large thermal inertia of the ground, the heat transfer is represented by a steady-state, or average component, together with an annual periodic component. The steady-state component is related to the difference between annual average internal temperature and annual average external temperature. The periodic component is related to the amplitude of the variation of the internal and external temperatures about their respective average values.

The internal and external temperatures are assumed to vary sinusoidally about their annual average values in the following form:

$$\theta_{\mathrm{i},m} = \overline{\theta}_{\mathrm{i}} - \hat{\theta}_{\mathrm{i}} \cos\left(2\pi \frac{m-\tau}{12}\right) \tag{A.1}$$

$$\theta_{\mathrm{e},m} = \overline{\theta}_{\mathrm{e}} - \hat{\theta}_{\mathrm{e}} \cos\left(2\pi \frac{m-\tau}{12}\right) \tag{A.2}$$

where

$\theta_{\mathrm{i},m}$ is the monthly mean internal temperature for month m, in °C;

$\overline{\theta}_{\mathrm{i}}$ is the annual average internal temperature, in °C;

$\hat{\theta}_{\mathrm{i}}$ is the amplitude of variations in monthly mean internal temperature, in K (as defined in 6.1);

$\theta_{\mathrm{e},m}$ is the monthly mean external temperature for month m, in °C;

$\overline{\theta}_{\mathrm{e}}$ is the annual average external temperature, in °C;

$\hat{\theta}_{\mathrm{e}}$ is the amplitude of variations in monthly mean external temperature, in K (as defined in 6.2);

m is the month number ($m = 1$ for January to $m = 12$ for December);

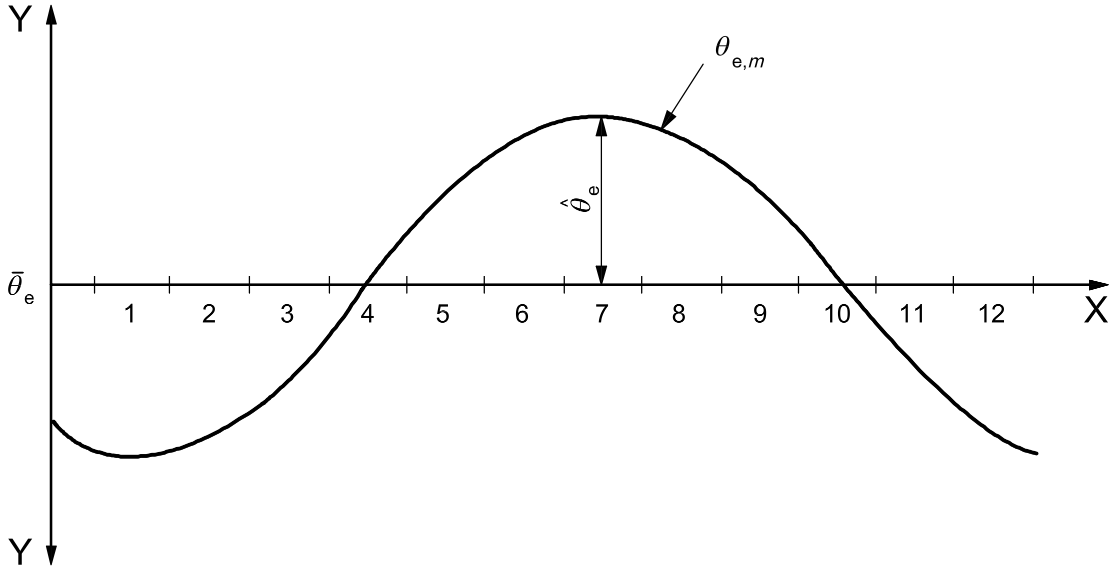
τ is the month number in which the minimum external temperature occurs (if appropriate, τ may be expressed as a decimal number).

τ should be assessed from consideration of the average external temperature for each month; shorter term fluctuations should not be included. It can be based on climatological information for the country or location concerned, expressed in whole months or a fraction of a month depending on the information available. In the absence of specific information, use $\tau = 1$ in the northern hemisphere and $\tau = 7$ in the southern hemisphere.

NOTE 1 $\tau = 1$ assumes the minimum temperature occurs in the middle of January and the maximum temperature in the middle of July, and $\tau = 7$ assumes the converse. This is a good approximation for many climates.

NOTE 2 Only the annual average temperature and the annual amplitude are required for calculations. These quantities can be derived from monthly values.

Figure A.1 illustrates the definitions of $\bar{\theta}_e$ and $\hat{\theta}_e$. The same applies to the internal temperature.



Key

X	month number, m ($m = 1$ for January to $m = 12$ for December)
Y	temperature, θ
$\bar{\theta}_e$	annual average external temperature
$\hat{\theta}_e$	amplitude of variations in monthly mean external temperature
$\theta_{e,m}$	monthly mean external temperature for month m

Figure A.1 — Illustration of the variation of external temperature over a year (in northern hemisphere)

The average rate of heat flow in month m is then given by

$$\Phi_m = H_g\left(\bar{\theta}_i - \bar{\theta}_e\right) - H_{pi}\,\hat{\theta}_i \cos\left(2\pi\frac{m-\tau+\alpha}{12}\right) + H_{pe}\,\hat{\theta}_e \cos\left(2\pi\frac{m-\tau-\beta}{12}\right) \qquad \text{(A.3)}$$

where

H_g is the steady-state ground heat transfer coefficient, in W/K;

H_{pi} is the internal periodic heat transfer coefficient, in W/K;

H_{pe} is the external periodic heat transfer coefficient, in W/K;

α is the time lead of the heat flow cycle compared with that of the internal temperature, in months;

β is the time lag of the heat flow cycle compared with that of the external temperature, in months.

H_{pi} and H_{pe} include the effect of thermal bridging at the floor edge. If they are calculated without the effect of edge-related heat transfer, a term $P \cdot \Psi_{\mathrm{g}}$ shall be added to each of them (see Clause 4).

NOTE 3 The periodic heat flow cycle leads the internal temperature variation and lags the external temperature variation. In this International Standard, α and β are both positive numbers; the lead/lag is taken into account in the way Equation (A.3) is written.

Annex F gives approximate methods of calculation of the coefficients H_{pi} and H_{pe} and the phase differences α and β. The formulae in Annex F for H_{pe} apply to cases without edge-related heat transfer. For detailed calculation of H_{pe}, see ISO 10211.

Equation (A.3) assumes that the annual variation of internal temperature is such that θ_{i} is lower in winter than in summer. If the reverse applies, $\hat{\theta}_{\mathrm{i}}$ should be taken as negative.

NOTE 4 For calculations based on an assumption of constant internal temperature, $\hat{\theta}_{\mathrm{i}} = 0$ and H_{pi} need not be considered.

A.3 Monthly heat flow rate using monthly average temperatures

Where mean monthly internal and external temperatures are known, the monthly heat flow rate is calculated by

$$\Phi_m = H_{\mathrm{g}}\left(\bar{\theta}_{\mathrm{i}} - \bar{\theta}_{\mathrm{e}}\right) - H_{\mathrm{pi}}(\bar{\theta}_{\mathrm{i}} - \theta_{\mathrm{i},m}) + H_{\mathrm{pe}}(\bar{\theta}_{\mathrm{e}} - \theta_{\mathrm{e},m}) \qquad \text{(A.4)}$$

where it is assumed that the phase differences α and β (see A.2) are zero.

A.4 Average heat flow rate over heating season or cooling season

For seasonal heat transfer calculations, the effect of the phase difference between the heat flow and the temperature variations can usually be ignored. The average rate of ground heat flow over a heating season is then determined from the average of the cosine terms in Equation (A.3) over the heating season:

$$\bar{\Phi} = H_{\mathrm{g}}\left(\bar{\theta}_{\mathrm{i}} - \bar{\theta}_{\mathrm{e}}\right) - \gamma H_{\mathrm{pi}}\hat{\theta}_{\mathrm{i}} + \gamma H_{\mathrm{pe}}\hat{\theta}_{\mathrm{e}} \qquad \text{(A.5)}$$

where the value of γ, which depends on the length of the heating season, is given by Equation (A.6):

$$\gamma = \frac{12}{n\,\pi}\sin\left(\frac{n\,\pi}{12}\right) \qquad \text{(A.6)}$$

where n is the number of months in the heating season.

Equation (A.5) assumes that the annual variation of internal temperature is such that θ_{i} is lower in winter than in summer. If the reverse applies, $\hat{\theta}_{\mathrm{i}}$ should be taken as negative.

NOTE For calculations based on an assumption of constant internal temperature, $\hat{\theta}_{\mathrm{i}} = 0$ and H_{pi} need not be considered.

The use of Equation (A.5) is appropriate for heat loss calculations made on a seasonal, rather than a monthly, basis.

Equation (A.5) can also be used for heat loss calculations made on a monthly basis, in cases where the variation in ground losses between months is not required. This has the effect of treating the ground losses as a constant term, thus overestimating these losses at the ends of the heating season and underestimating the losses at the middle of the heating season.

The average rate of heat flow over the cooling season is calculated similarly:

$$\bar{\Phi} = H_\mathrm{g}\left(\bar{\theta}_\mathrm{i} - \bar{\theta}_\mathrm{e}\right) + \gamma H_\mathrm{pi}\hat{\theta}_\mathrm{i} - \gamma H_\mathrm{pe}\hat{\theta}_\mathrm{e} \tag{A.7}$$

with γ from Equation (A.6) using the number of months in the cooling season for n.

A.5 Annual average heat flow rate

If $\hat{\theta}_\mathrm{i}$, $\hat{\theta}_\mathrm{e}$ or the length of the heating season is not known, or if the ground losses are required only approximately, the ground heat flow rate can be taken as a constant term equal to the steady-state component:

$$\bar{\Phi} = H_\mathrm{g}\left(\bar{\theta}_\mathrm{i} - \bar{\theta}_\mathrm{e}\right) \tag{A.8}$$

This is often an adequate approximation, especially if the heating season is long or if $\hat{\theta}_\mathrm{i}$ and $\hat{\theta}_\mathrm{e}$ have opposite effects on the heat flow.

A.6 Maximum monthly heat flow rate

The maximum monthly heat flow rate is given by

$$\Phi_\mathrm{max} = H_\mathrm{g}\left(\bar{\theta}_\mathrm{i} - \bar{\theta}_\mathrm{e}\right) + H_\mathrm{pe}\hat{\theta}_\mathrm{e} \tag{A.9}$$

NOTE This expression corresponds to a constant internal temperature and the maximum contribution from the external temperature variation.

A.7 Monthly ground heat transfer coefficient

The ground heat transfer coefficient, $H_{\mathrm{g},m}$, in month m is given by

$$H_{\mathrm{g},m} = \frac{\Phi_m}{\theta_{\mathrm{i},m} - \theta_{\mathrm{e},m}} \tag{A.10}$$

A.8 Total heat transfer during heating season or cooling season

The total heat transfer via the ground is the integral of the heat flow rate, which can be represented by a sum of monthly values:

$$Q = \sum_{m=m_1}^{m_2} Q_m \tag{A.11}$$

$$Q_m = 86\,400 \times N_m \Phi_m \tag{A.12}$$

where

Q is the total heat transfer, in J;

Q_m is the heat transfer in month m, in J;

N_m is the number of days in month m;

Φ_m is the rate of heat transfer in month m, in W;

m_1 is the first month of the heating or cooling season;

m_2 is the last month of the heating or cooling season;

86 400 is the number of seconds in one day.

In the case of an average heat flow rate from Equation (A.4) or Equation (A.7):

$$Q = 86\,400 \times N \bar{\Phi} \tag{A.13}$$

where N is the total number of days in the heating season.

Annex B
(normative)

Slab-on-ground with edge insulation

B.1 General

A slab-on-ground floor can have edge insulation, placed either horizontally or vertically along the perimeter of the floor. The formulae given in this annex are applicable when the width or depth of the edge insulation, D, is small compared to the width of the building.

Numerical methods may be used as an alternative. Where numerical calculations of linear thermal transmittance incorporate the effect of any edge insulation, calculations in accordance with this annex shall not be included in addition.

The effect of edge insulation is treated as a linear thermal transmittance, $\Psi_{\mathrm{g,e}}$, which is obtained in accordance with B.2 for horizontal edge insulation, or in accordance with B.3 for vertical edge insulation. Low-density foundations, of thermal conductivity less than that of the soil, are treated as vertical edge insulation. $\Psi_{\mathrm{g,e}}$ has a negative value.

If the foundation detail has more than one piece of edge insulation (vertically or horizontally, internally or externally), calculate $\Psi_{\mathrm{g,e}}$ by the procedures below for each edge insulation separately, and use that giving the greatest reduction in heat loss.

NOTE 1 The formulae given in this annex provide good estimates of the effect of adding edge insulation to uninsulated floors. They underestimate the effect of adding additional edge insulation to an already insulated floor, but can nevertheless be used: the effect of the edge insulation will be at least that predicted.

Equations (B.5) and (B.6) include the additional equivalent thickness resulting from the edge insulation, d', defined as:

$$d' = R'\lambda \tag{B.1}$$

where R' is the additional thermal resistance introduced by the edge insulation (or foundation), i.e. the difference between the thermal resistance of the edge insulation and that of the soil (or slab) it replaces:

$$R' = R_{\mathrm{n}} - \frac{d_{\mathrm{n}}}{\lambda} \tag{B.2}$$

where

R_{n} is the thermal resistance of the horizontal or vertical edge insulation (or foundation), in $\mathrm{m^2 \cdot K/W}$;

d_{n} is the thickness of the edge insulation (or foundation), in m.

When $\Psi_{\mathrm{g,e}}$ is included in the calculation, Equation (1) in this International Standard is modified to:

$$H_{\mathrm{g}} = (AU) + P\left(\Psi_{\mathrm{g}} + \Psi_{\mathrm{g,e}}\right) \tag{B.3}$$

For steady-state calculations, the effect of the edge insulation may be incorporated into the thermal transmittance of the floor using Equation (B.4).

$$U = U_0 + \frac{2\Psi_{g,e}}{B'} \tag{B.4}$$

where U_0 is the thermal transmittance of the floor without edge insulation, in which case Equation (1) applies for calculation of the steady-state ground heat transfer coefficient.

NOTE 2 Any all-over insulation of the floor slab is included in the calculation of U_0.

NOTE 3 Both Ψ_g and $\Psi_{g,e}$ are included in H_{pi} and H_{pe} (see Annex A).

B.2 Horizontal edge insulation

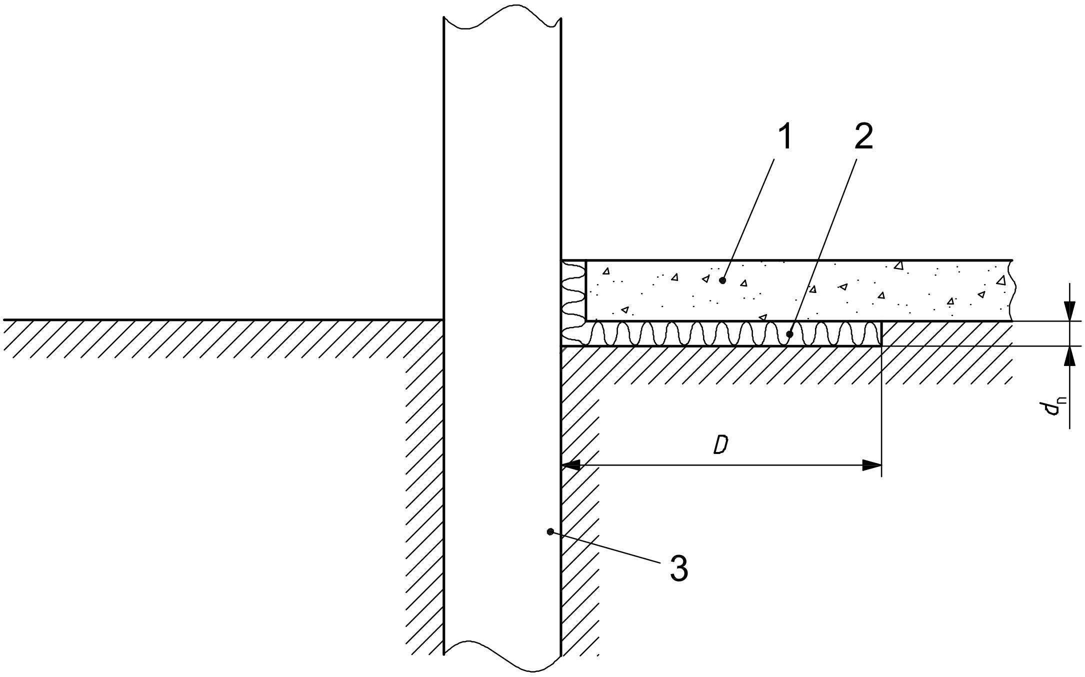
Equation (B.5) applies to insulation placed horizontally along the perimeter of the floor (see Figure B.1):

$$\Psi_{g,e} = -\frac{\lambda}{\pi}\left[\ln\left(\frac{D}{d_t}+1\right) - \ln\left(\frac{D}{d_t + d'}+1\right)\right] \tag{B.5}$$

where

D is the width of horizontal edge insulation, in m;

d' is as defined in Equation (B.1).



Key

1 floor slab
2 horizontal edge insulation
3 foundation wall

d_n thickness of the edge insulation (or foundation)
D width of horizontal edge insulation

Figure B.1 — Schematic diagram of horizontal edge insulation

Figure B.1 shows edge insulation below the slab. Equation (B.5) also applies to horizontal edge insulation above the slab or external to the building.

B.3 Vertical edge insulation

Equation (B.6) applies to insulation placed vertically below ground along the perimeter of the floor (see Figure B.2), and to foundations of material of lower thermal conductivity than the ground (see Figure B.3):

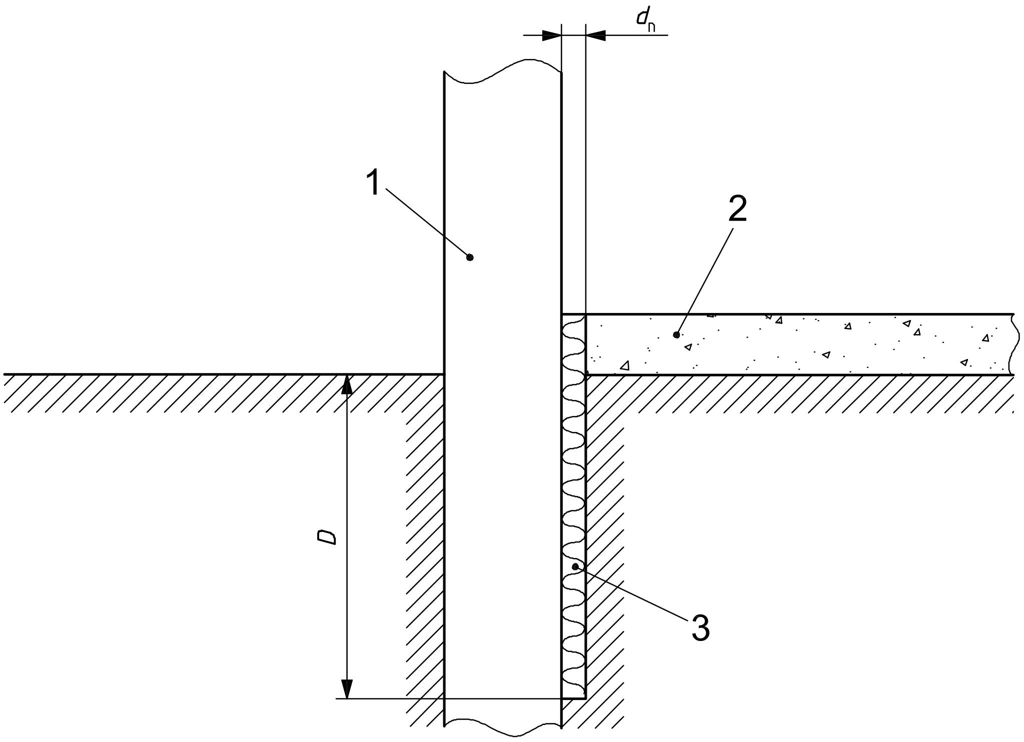
$$\Psi_{\mathrm{g,e}} = -\frac{\lambda}{\pi}\left[\ln\left(\frac{2D}{d_{\mathrm{t}}}+1\right)-\ln\left(\frac{2D}{d_{\mathrm{t}}+d'}+1\right)\right] \tag{B.6}$$

where

D is the depth of vertical edge insulation (or foundation) below ground level, in m;

d' is as defined in Equation (B.1).

Figure B.2 shows edge insulation inside the foundation wall. Equation (B.6) also applies to vertical edge insulation outside or within the foundation wall.

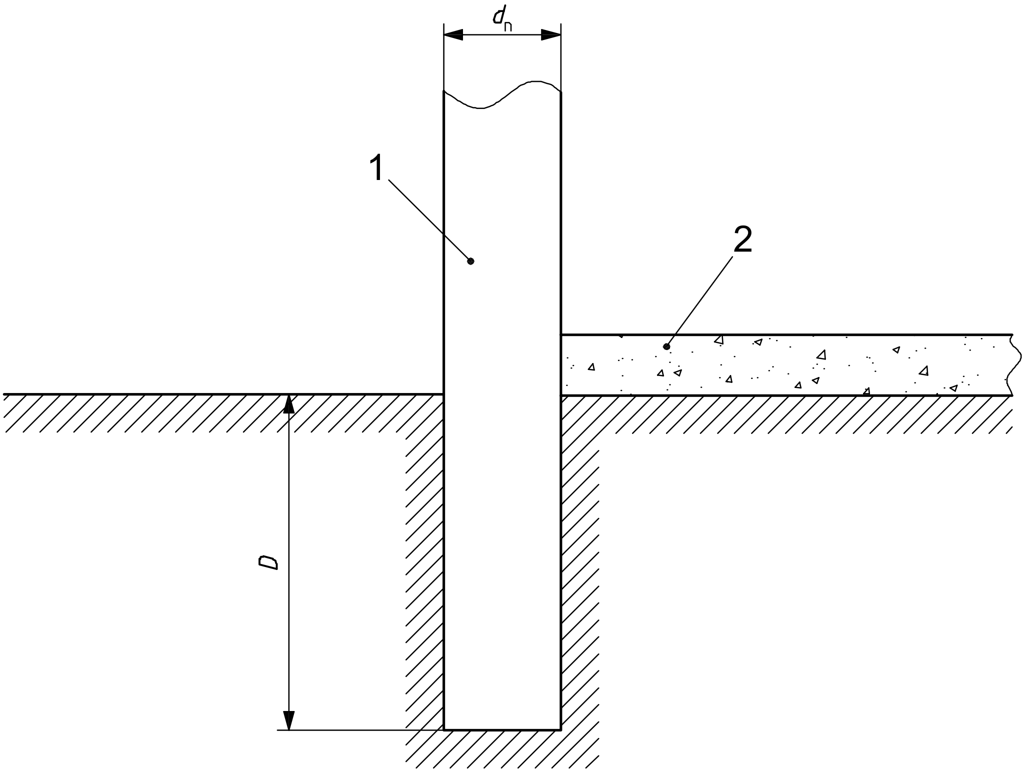


Key

1 foundation wall
2 floor slab
3 vertical edge insulation

d_n thickness of the edge insulation (or foundation)
D depth of vertical edge insulation (or foundation) below ground level

Figure B.2 — Vertical edge insulation (insulation layer)



Key

1 low density foundation wall with $\lambda_n < \lambda$

2 floor slab

d_n thickness of the edge insulation (or foundation)

D depth of vertical edge insulation (or foundation) below ground level

Figure B.3 — Vertical edge insulation (low density foundation)

Annex C
(normative)

Heat flow rates for individual rooms

The formulae in this International Standard give the total heat flow rate through the whole floor. When the heat flow rate is required for individual rooms of a building, in which some rooms have external walls and some do not, the heat flow through the floor may be divided into two parts, applicable respectively to rooms having external walls (the edge region) and rooms having no external walls (the central region). To obtain the total heat flow for individual rooms, add the contribution due to the walls and other elements.

The steady-state heat flow rate is first calculated for the whole floor, Φ_t. This is then divided into heat flow rate for the edge region, Φ_e, and for the central region, Φ_m, as follows:

$$\Phi_e = \Phi_t \frac{A_e}{A_m \dfrac{b + d_t}{0{,}5 \times B' + d_t} + A_e} \tag{C.1}$$

$$\Phi_m = \Phi_t - \Phi_e \tag{C.2}$$

$$q_e = \frac{\Phi_e}{A_e} \tag{C.3}$$

$$q_m = \frac{\Phi_m}{A_m} \tag{C.4}$$

where

q_e is the density of heat flow rate for rooms at the edge of the building;

q_m is the density of heat flow rate for rooms in the middle of the building;

A_e is the total floor area of rooms at the edge of the building;

A_m is the total floor area of rooms in the middle of the building;

b is the average width of rooms at the edge of the building;

B' is the characteristic dimension of the whole floor as defined in 8.1.

Periodic heat transfer due to annual variation in external temperature should be applied only to rooms at the edge of the building.

Annex D

(normative)

Application to dynamic simulation programmes

This annex gives a method of treating heat transfers via the ground in connection with transient methods for the calculation of heat flows or temperatures in buildings, using a time step of one hour or less.

The floor construction together with the ground is modelled as a single component, consisting of each layer in the floor construction plus 0,5 m depth of ground plus a virtual layer.

The virtual layer is included so that the annual average heat flow is correct. It has a thermal resistance R_v and has negligible thermal capacity. R_v is calculated from Equation (D.1):

$$R_\mathrm{v} = \frac{1}{U} - R_\mathrm{si} - R_\mathrm{f} - R_\mathrm{g} \qquad \text{(D.1)}$$

where

U is the steady-state thermal transmittance of the floor including the effect of the ground, calculated by the methods in this International Standard or by a numerical method using the boundary conditions and assumptions applicable to calculation of U by this International Standard;

R_si is the internal surface resistance of the floor;

R_f is the total thermal resistance of all layers in the floor construction;

R_g is the thermal resistance of 0,5 m of ground.

For the purposes of the thermal model, the virtual layer can be assigned a thickness of 0,1 m so that its thermal conductivity is $0{,}1/R_\mathrm{v}$. Its density and specific heat capacity should be zero or very small values (of 1 kg/m^3 and 1 J/(kg·K) respectively).

The boundary condition at the bottom of the virtual layer is a virtual temperature, θ_v.

θ_v can be assigned for each month of the year according to

$$\theta_{\mathrm{v},m} = \theta_{\mathrm{i},m} - \frac{\Phi_m}{AU} \qquad \text{(D.2)}$$

where Φ_m is calculated in accordance with Annex A.

NOTE This includes any edge related heat transfer.

Equation (D.2) is usually an adequate approximation. Alternatively, θ_v can be calculated using a numerical method for different time steps:

$$\theta_{\mathrm{v},t} = \theta_{\mathrm{i},t} - \frac{\Phi_t}{AU} \qquad \text{(D.3)}$$

where Φ_t is calculated at time t, using a numerical method.

Annex E
(normative)

Ventilation below suspended floors

E.1 General expressions for average temperature and thermal transmittance

Heat incoming through the suspended floor into the underfloor space is transferred from the underfloor space to the external environment in three ways:

a) through the ground,

b) through the wall (above ground level) of the underfloor space;

c) by ventilation of the underfloor space.

A steady-state heat balance of the above heat flows gives the average temperature of the underfloor space as follows:

$$\bar{\theta}_{\mathrm{us}} = \frac{A U_{\mathrm{f}}\, \bar{\theta}_{\mathrm{i}} + \dot{V} c_p\, \rho \bar{\theta}_{\mathrm{v}} + \left(A U_{\mathrm{g}} + h P U_{\mathrm{w}} \right) \bar{\theta}_{\mathrm{e}}}{A U_{\mathrm{f}} + \dot{V} c_p\, \rho + A U_{\mathrm{g}} + h P U_{\mathrm{w}}} \qquad \text{(E.1)}$$

where

$\bar{\theta}_{\mathrm{us}}$ is the annual average temperature in underfloor space, in °C.

$\bar{\theta}_{\mathrm{i}}$ is the annual average internal temperature, in °C;

$\bar{\theta}_{\mathrm{e}}$ is the annual average external temperature, in °C;

$\bar{\theta}_{\mathrm{v}}$ is the annual average temperature of ventilating air, in °C;

U_{f} is the thermal transmittance of the suspended part of floor, in W/(m²·K);

U_{g} is the thermal transmittance of the ground, in W/(m²·K);

U_{w} is the thermal transmittance of walls of underfloor space (above ground level), in W/(m²·K);

$\dot{V}$ is the volumetric air change rate, in m³/s;

h is the height of suspended floor above ground level, in m;

c_p is the specific heat capacity of air at constant pressure, in J/(kg·K);

ρ is the density of air, in kg/m³.

U_{g} should be obtained by the method in 9.2 if the depth of the base of the underfloor space below ground level, z, does not exceed 0,5 m. If $z > 0{,}5$ m, methods analogous to those in 9.3 can be used, so that

$$U_{\mathrm{g}} = U_{\mathrm{bf}} + \frac{z P U_{\mathrm{bw}}}{A} \qquad \text{(E.2)}$$

where U_{bf} and U_{bw} are obtained as specified in 9.3.

The thermal transmittance of the floor (between internal and external environments) is given by Equation (E.3):

$$U = U_{\mathrm{f}} \frac{A U_{\mathrm{g}} + h P U_{\mathrm{w}} + \dot{V} c_p \rho \left(\bar{\theta}_{\mathrm{i}} - \bar{\theta}_{\mathrm{v}}\right) / \left(\bar{\theta}_{\mathrm{i}} - \bar{\theta}_{\mathrm{e}}\right)}{A U_{\mathrm{f}} + A U_{\mathrm{g}} + h P U_{\mathrm{w}} + \dot{V} c_p \rho} \quad \text{(E.3)}$$

Equations (E.2) and (E.3) can also be used for unheated basements.

E.2 Ventilation rate

$\dot{V}$ (m^3/s) is specified for mechanically ventilated floors.

For naturally ventilated floors,

$$\dot{V} = 0{,}59 \times \varepsilon v f_{\mathrm{w}} P \quad \text{(E.4)}$$

where

ε is the area of ventilation opening per perimeter length, in m^2/m;

v is the design wind speed at 10 m height, in m/s;

f_{w} is the wind shielding factor defined in 9.2.

For calculations using this International Standard,

c_p = 1 000 J/(kg·K) (at 10 °C);

ρ = 1,23 $\mathrm{kg/m}^3$ (at 10 °C and 100 kPa pressure).

E.3 Natural ventilation

In this case, $\bar{\theta}_{\mathrm{v}} = \bar{\theta}_{\mathrm{e}}$ and re-arrangement of Equation (E.3), together with Equation (E.4), gives the formulae in 9.2.

E.4 Mechanical ventilation from inside

In this case, $\bar{\theta}_{\mathrm{v}} = \bar{\theta}_{\mathrm{i}}$ and from Equation (E.3):

$$\frac{1}{U} = \frac{1}{U_{\mathrm{f}}} + \frac{1 + \dot{V} c_p \rho / A U_{\mathrm{f}}}{U_{\mathrm{g}} + 2 h U_{\mathrm{w}} / B'} \quad \text{(E.5)}$$

E.5 Mechanical ventilation from outside

In this case, $\bar{\theta}_{\mathrm{v}} = \bar{\theta}_{\mathrm{e}}$ and from Equation (E.3):

$$\frac{1}{U} = \frac{1}{U_{\mathrm{f}}} + \frac{1}{U_{\mathrm{g}} + 2 h U_{\mathrm{w}} / B' + \dot{V} c_p \rho / A} \quad \text{(E.6)}$$

E.6 Unventilated underfloor space

In this case, $\dot{V} = 0$ and from Equation (E.3):

$$\frac{1}{U} = \frac{1}{U_\mathrm{f}} + \frac{1}{U_\mathrm{g} + 2hU_\mathrm{w}/B'} \qquad \text{(E.7)}$$

E.7 Unheated basements

Equation (E.6) applies with $\dot{V} c_p \rho = 0{,}34 \times nV$.

Annex F
(informative)

Periodic heat transfer coefficients

F.1 General

This annex gives formulae for the periodic heat transfer coefficients H_{pi} and H_{pe} defined in Annex A. The formulae for H_{pi} may be used for floors whose construction is uniform over the whole floor area. The formulae for H_{pe} are approximations for idealised wall/floor junctions. They are suitable for uninsulated floors, and for insulated floors with negligible thermal bridging at the edges of the floor. For other cases, values can be obtained by numerical methods (see ISO 10211).

F.2 Periodic penetration depth

The periodic heat transfer coefficients are related to the periodic penetration depth, δ, the depth in the ground at which (for one-dimensional heat flow) the temperature amplitude is reduced to 1/e of that at the surface, where e is the base of natural logarithms (e = 2,718). For an annual temperature cycle, δ is given by

$$\delta = \sqrt{\frac{3{,}15 \times 10^7 \times \lambda}{\pi \rho c}} \tag{F.1}$$

NOTE 3,15 × 10^7 is the number of seconds in a year.

Table F.1 gives approximate values of δ which may be used for calculations by this International Standard.

Table F.1 — Periodic penetration depth

Category	Description	δ m
1	clay or silt	2,2
2	sand or gravel	3,2
3	homogeneous rock	4,2

F.3 Phase differences

Equations (F.2) and (F.3) give approximate values of the phase differences for slab-on-ground floors:

$$\alpha = 1{,}5 - \frac{12}{2\pi}\arctan\left(\frac{d_{\text{t}}}{d_{\text{t}} + \delta}\right) \tag{F.2}$$

$$\beta = 1{,}5 - 0{,}42 \times \ln\left(\frac{\delta}{d_{\text{t}} + 1}\right) \tag{F.3}$$

Edge insulation of a slab-on-ground floor can significantly increase the time lag compared with the external temperature variation, especially if placed vertically or external to the building.

For suspended floors, the effects are less because the ventilation heat flow has no time lag.

For basements of depth comparable with or greater than δ, Equations (F.2) and (F.3) apply, with d_t replaced by d_w.

The precise value of the time lead or lag between the heat flow and the temperature variations does not significantly affect the result of energy calculations. Indicative values of the phase difference, to the nearest month, are given in Table F.2. These are suitable for most calculation purposes and, in practice, only small errors result if the time lag or lead is omitted (temperatures and heat flow taken to be in phase).

Table F.2 — Phase differences (in months)

Type of floor	α	β
Slab-on-ground, no edge insulation	0	1
Slab-on-ground with internal horizontal edge insulation	0	1
Slab-on-ground with vertical or external edge insulation	0	2
Suspended floor	0	0
Basement (heated or unheated)	0	1

F.4 Slab-on-ground floor: uninsulated or with all-over insulation

F.4.1 Internal temperature variation

The periodic heat transfer coefficient related to internal temperature variations over an annual cycle is

$$H_\mathrm{pi} = A \frac{\lambda}{d_\mathrm{t}} \sqrt{\frac{2}{\left(1+\delta/d_\mathrm{t}\right)^2+1}} \tag{F.4}$$

F.4.2 External temperature variation

The periodic heat transfer coefficient related to external temperature variations over an annual cycle is

$$H_\mathrm{pe} = 0{,}37 \times P\lambda \ln\left(\frac{\delta}{d_\mathrm{t}}+1\right) \tag{F.5}$$

F.5 Slab-on-ground with edge insulation

F.5.1 Internal temperature variation

Ignore the edge insulation and calculate H_pi according to Equation (F.4).

F.5.2 External temperature variation

H_pe consists of two terms, one related to the edge of the floor and the other related to the middle of the floor.

For floors incorporating horizontal edge insulation,

$$H_{\mathrm{pe}} = 0{,}37 \times P\lambda \left[\left(1 - \mathrm{e}^{-D/\delta}\right) \ln\left(\frac{\delta}{d_{\mathrm{t}} + d'} + 1\right) + \mathrm{e}^{-D/\delta} \ln\left(\frac{\delta}{d_{\mathrm{t}}} + 1\right) \right] \tag{F.6}$$

where

D is the width of horizontal edge insulation, in m;

d_{t} is as defined in 9.1;

d' is as defined in Annex B.

For floors incorporating vertical edge insulation,

$$H_{\mathrm{pe}} = 0{,}37 \times P\lambda \left[\left(1 - \mathrm{e}^{-2D/\delta}\right) \ln\left(\frac{\delta}{d_{\mathrm{t}} + d'} + 1\right) + \mathrm{e}^{-2D/\delta} \ln\left(\frac{\delta}{d_{\mathrm{t}}} + 1\right) \right] \tag{F.7}$$

where

D is the depth of vertical edge insulation (or foundation) below ground level, in m.

If the foundation detail has more than one piece of edge insulation (vertically or horizontally, internally or externally), calculate H_{pe} by the procedures above for each edge insulation separately, and use the lowest value.

F.6 Suspended floor

F.6.1 General

In the calculation of the periodic coefficients, use U_{f}, U_{x} and d_{g}, as defined in 9.2.

F.6.2 Internal temperature variation

$$H_{\mathrm{pi}} = A \left[\frac{1}{U_{\mathrm{f}}} + \frac{1}{\lambda/\delta + U_{\mathrm{x}}} \right]^{-1} \tag{F.8}$$

F.6.3 External temperature variation

$$H_{\mathrm{pe}} = U_{\mathrm{f}} \frac{0{,}37 \times P\lambda \ln\left(\delta/d_{\mathrm{g}} + 1\right) + U_{\mathrm{x}} A}{\lambda/\delta + U_{\mathrm{x}} + U_{\mathrm{f}}} \tag{F.9}$$

F.7 Heated basement

F.7.1 Internal temperature variation

The periodic heat transfer coefficient due to internal temperature variations over an annual cycle consists of two terms, one related to the floor of the basement and the other related to the walls of the basement:

$$H_{\mathrm{pi}} = A \frac{\lambda}{d_{\mathrm{t}}} \sqrt{\frac{2}{\left(1 + \delta/d_{\mathrm{t}}\right)^2 + 1}} + zP \frac{\lambda}{d_{\mathrm{w}}} \sqrt{\frac{2}{\left(1 + \delta/d_{\mathrm{w}}\right)^2 + 1}} \tag{F.10}$$

F.7.2 External temperature variation

The periodic heat transfer coefficient due to external temperature variations over an annual cycle consists of two terms, one related to the floor of the basement and the other related to the walls of the basement:

$$H_{\text{pe}} = 0{,}37 \times P\lambda \left[\mathrm{e}^{-z/\delta} \ln\left(\frac{\delta}{d_{\text{t}}} + 1 \right) + 2\left(1 - \mathrm{e}^{-z/\delta}\right) \ln\left(\frac{\delta}{d_{\text{w}}} + 1 \right) \right] \tag{F.11}$$

F.8 Unheated basement

F.8.1 Internal temperature variation

$$H_{\text{pi}} = \left[\frac{1}{AU_{\text{f}}} + \frac{1}{(A + zP)\lambda/\delta + hPU_{\text{w}} + 0{,}33 \times nV} \right]^{-1} \tag{F.12}$$

F.8.2 External temperature variation

$$H_{\text{pe}} = AU_{\text{f}} \frac{0{,}37 \times P\lambda \left(2 - \mathrm{e}^{-z/\delta}\right) \ln\left(\delta/d_{\text{t}} + 1\right) + hPU_{\text{w}} + 0{,}33 \times nV}{(A + zP)\lambda/\delta + hPU_{\text{w}} + 0{,}33 \times nV + AU_{\text{f}}} \tag{F.13}$$

Annex G
(informative)

Thermal properties of the ground

The thermal properties of the ground depend on several factors, including density, degree of water saturation, particle size, type of mineral constituting the particles, and whether frozen or unfrozen. As a result, the thermal properties vary considerably from one location to another, and at different depths at a given location, and also may vary with time due to changes in moisture content or due to freezing and thawing.

Values of the properties of the ground used for heat transfer calculations, including measured values, should be representative of the ground in the vicinity of the building and over the period of time to which the calculation refers (e.g. the heating season).

Table G.1 indicates the range of thermal conductivity for various types of unfrozen ground, and shows the representative values specified in 5.1.

Table G.1 — Thermal conductivity of ground

Ground type	**Dry density** ρ kg/m^3	**Moisture content** u kg/kg	**Degree of saturation** %	**Thermal conductivity** λ W/(m·K)	**Representative value of** λ W/(m·K)
silt	1 400 to 1 800	0,10 to 0,30	70 to 100	1,0 to 2,0	1,5
clay	1 200 to 1 600	0,20 to 0,40	80 to 100	0,9 to 1,4	1,5
peat	400 to 1 100	0,05 to 2,00	0 to 100	0,2 to 0,5	—
dry sand	1 700 to 2 000	0,04 to 0,12	20 to 60	1,1 to 2,2	2,0
wet sand	1 700 to 2 100	0,10 to 0,18	85 to 100	1,5 to 2,7	2,0
rock	2 000 to 3 000	[a]	[a]	2,5 to 4,5	3,5

[a] Usually very small (moisture content < 0,03 mass), except for porous rocks.

The heat capacity per volume, ρc, can be obtained from the following equation:

$$\rho c = \rho \left(c_{\text{s}} + c_{\text{w}} u \right) \quad \text{(G.1)}$$

where

c is the specific heat capacity of the ground , in J/(kg·K);

ρ is the dry density, in kg/m^3;

c_{s} is the specific heat capacity of minerals, in J/(kg·K);

c_{w} is the specific heat capacity of water, in J/(kg·K);

u is the moisture content mass by mass referred to the dry state, in kg/kg.

For most minerals, $c_{\text{s}} \approx$ 1 000 J/(kg·K), and $c_{\text{w}} =$ 4 180 J/(kg·K) at 10 °C.

The representative values of ρc specified in 5.1 are obtained from Equation (G.1), as follows (rounding to one significant figure):

- clay/silt: $\rho c = 1\,600 \times (1\,000 + 4\,180 \times 0{,}20) = 2{,}94 \times 10^6 \rightarrow 3 \times 10^6$
- sand: $\rho c = 1\,800 \times (1\,000 + 4\,180 \times 0{,}05) = 2{,}18 \times 10^6 \rightarrow 2 \times 10^6$
- rock: $\rho c = 2\,500 \times 800 = 2{,}00 \times 10^6 \rightarrow 2 \times 10^6$

Annex H
(informative)

The influence of flowing ground water

The effect of flowing ground water can be assessed by multiplying the steady-state heat flow rate by a factor, G_w. To determine the factor, knowledge is required of the depth of the water table and the rate of ground water flow. For slab-on-ground floors and basements, G_w multiplies the steady-state ground heat transfer coefficient, H_g. For suspended floors, G_w multiplies the ground thermal transmittance, U_g. The factor should not be applied to the periodic heat transfer coefficients, H_{pi} and H_{pe}.

Values of G_w are given in Table H.1 as a function of the dimensionless ratios $\frac{z_w}{B'}$, $\frac{l_c}{B'}$ and $\frac{d_t}{B'}$, where

z_w is the depth of the water table below ground level, in m;

l_c is a calculation length which relates the heat flow by conduction to the heat flow due to ground water, in m.

The length l_c is given by

$$l_c = \frac{\lambda}{\rho_w c_w q_w} \qquad \text{(H.1)}$$

where

q_w is the mean drift velocity of the ground water, in m/s;

ρ_w is the density of water, in kg/m^3;

c_w is the specific heat capacity of water, in J/(kg·K).

NOTE 1 $\rho_w c_w = 4,18 \times 10^6$, in J/(m^3·K) at 10°C.

NOTE 2 If $l_c >> B'$, the conduction heat flow predominates. If $l_c << B'$, the ground water heat flow predominates.

Table H.1 — Values of G_w

z_w/B'	l_c/B'	G_w		
		$d_t/B' = 0{,}1$	$d_t/B' = 0{,}5$	$d_t/B' = 1{,}0$
0,0	1,0	1,01	1,01	1,00
0,0	0,2	1,16	1,11	1,07
0,0	0,1	1,33	1,20	1,13
0,0	0,0	—	1,74	1,39
0,5	1,0	1,00	1,00	1,00
0,5	0,1	1,06	1,04	1,02
0,5	0,02	1,11	1,07	1,05
0,5	0,0	1,20	1,12	1,08
1,0	0,1	1,05	1,03	1,02
2,0	0,0	1,02	1,01	1,00

Annex I
(informative)

Slab-on-ground floor with an embedded heating or cooling system

The heat flow rate from a floor incorporating an embedded heating or cooling system whose heat output is uniformly distributed can be calculated in accordance with the methods in this International Standard, with the following modifications:

- replace the internal temperature, T_i, by the average temperature in the plane of the heating elements, T_h;
- include in the calculation of d_t only any thermal resistance below the heating/cooling element, the wall thickness and the external surface resistance.

The average temperature in the plane of the heating/cooling elements is usually not known, because it is the room temperature that is controlled and the system may be operated intermittently (night set-back or night switch-off). In such cases, the average floor surface temperature can be estimated in one of the ways described below.

a) If the average rate of heat input to (or extract from) the floor heating system, Φ_h, is known, first calculate the heat flow rate through the floor using the room temperature as the internal temperature and call this Φ_1. Then calculate the average temperature in the plane of the heating element, θ_h, from

$$\theta_\mathrm{h} = \theta_\mathrm{i} + R_\mathrm{i} \frac{(\Phi_\mathrm{h} - \Phi_1)}{A} \tag{I.1}$$

where

θ_i is the average room temperature, in °C;

R_i is the thermal resistance between the internal environment and the plane of the heating element, in $\mathrm{m^2 \cdot K/W}$;

A is the area of floor, in $\mathrm{m^2}$.

b) If the average rate of heat input to (or extract from) the floor heating system is not known, then perform a heat balance in the room (not including the ground heat losses), giving a net heat requirement of Φ_2. The average temperature in the plane of the heating element follows from

$$\theta_\mathrm{h} = \theta_\mathrm{i} + \frac{R_\mathrm{i} \Phi_2}{A} \tag{I.2}$$

Annex J
(informative)

Cold stores

J.1 Cold stores are refrigerated buildings in which the internal environment is kept below 0 °C.

It is necessary to protect the ground below the cold store from frost heave. For this reason, the floor of the cold store is insulated and heating is provided below the insulation to ensure that the ground is kept above 0 °C (5 °C is a common design temperature). The procedure in this annex can also be used for other analogous situations, such as ice rinks.

J.2 For the purposes of this International Standard, calculations are done assuming a constant temperature at the ground surface. (In summer, the ground temperature may rise above the design temperature, but the effect of this is minimal.)

Calculations may be required for

- sizing of the heating elements for the frost protection;
- sizing of the refrigeration plant;
- the annual energy used.

J.3 The relevant heat transfers are:

a) from the heating elements to the external environment (via the ground);

b) from the heating elements to the refrigerated space.

J.4 The heat flow rate via the ground may be calculated in accordance with the procedures in this International Standard, with the following modifications:

a) replace the internal temperature θ_i by the design temperature of the ground surface (e.g. 5 °C);

b) include in d_t only any thermal resistance below the heating element, the wall thickness and external surface resistance.

J.5 The heat flow rate from the heating elements to the refrigerated space is given by:

$$\Phi_f = A(\theta_g - \theta_i)/(R_{si} - R_i) \tag{J.1}$$

where

Φ_f is the heat flow rate, in W;

θ_i is the design internal temperature of the cold store, in °C;

θ_g is the design temperature of the ground surface, in °C;

R_i is the thermal resistance of all floor layers between the plane of the heating elements and the internal floor surface, in m²·K/W.

Annex K
(informative)

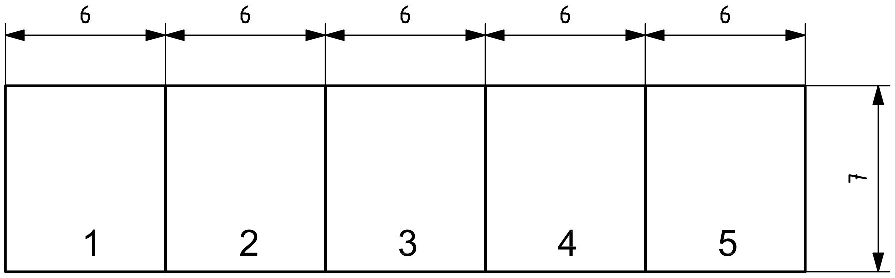
Worked examples

K.1 Example 1: Slab-on-ground, rectangular floor

K.1.1 Definition

Figure K.1 shows a terrace (or row) of five houses, numbered 1 to 5, with a slab-on-ground floor on clay-type soil; the floor dimensions are indicated; the floor is uninsulated; the wall thickness is 0,3 m.

Dimensions in metres



Key

1, 2, 3, 4, 5	house numbers

Figure K.1 — Row of houses

Calculate the steady-state ground heat transfer coefficient, H_g:

a) for the complete building (all five houses together);

b) for each of the five houses separately;

c) add together the results from b), then compare with a).

K.1.2 Whole building

$P = 30 + 7 + 30 + 7 = 74$ m, and $A = 7 \times 30 = 210$ m^2, so

$$B' = \frac{210}{0,5 \times 74} = 5,676 \text{ m}$$

For clay soil, $\lambda = 1,5$ W/(m·K), so

$$d_t = 0,3 + 1,5\,(0,17 + 0 + 0,04) = 0,615 \text{ m.}$$

$d_t < B'$, so

$$U = \frac{2 \times 1,5}{3,142 \times 5,676 + 0,615} \ln\left(\frac{3,142 \times 5,676}{0,615} + 1\right) = 0,1626 \times \ln(30,00) = 0,553 \text{ W/(m}^2 \cdot \text{K);}$$

$$H_g = 0,553 \times 210 = 116,1 \text{ W/K.}$$

K.1.3 Houses 1 and 5

P does not include the lengths of walls separating the part under consideration from other heated parts of the building, as described in 8.1.

$P = 6 + 7 + 6 = 19$ m, and $A = 42$ m^2, so $B' = 4{,}421$ m.

$d_t = 0{,}615$ m, as before.

This gives $U = 0{,}654$ W/(m^2·K) and $H_g = 27{,}4$ W/K.

K.1.4 Houses 2, 3 and 4

$P = 6 + 6 = 12$ m, and $A = 42$ m^2, so $B' = 7{,}0$ m.

$d_t = 0{,}615$ m, as before.

This gives $U = 0{,}478$ W/(m^2·K) and $H_g = 20{,}1$ W/K.

K.1.5 Comparison of whole building with sum for individual houses

Adding H_g for each house gives

$$2 \times 27{,}4 + 3 \times 20{,}1 = 115{,}1 \text{ W/K}$$

which is slightly different to the value of 116,1 W/K obtained when the building as a whole was assessed. This difference, of less than 1 %, is typical of the magnitude of the error resulting from applying the procedure to parts of a building rather than a complete building.

K.2 Example 2: Slab-on-ground: L-shaped building, various insulation possibilities

K.2.1 Definition

Figure K.2 shows an L-shaped dwelling with $w = 0{,}3$ m. The soil category is 2, so $\lambda = 2{,}0$ W/(m·K).

$$P = 10 + 6 + 6 + 3 + 4 + 9 = 38 \text{ m.}$$

The area is conveniently obtained as the sum of the areas of two rectangles:

$$A = (10 \times 6) + (3 \times 4) = 72 \text{ m}^2;$$

$$B' = 72/19 = 3{,}789 \text{ m.}$$

Dimensions in metres

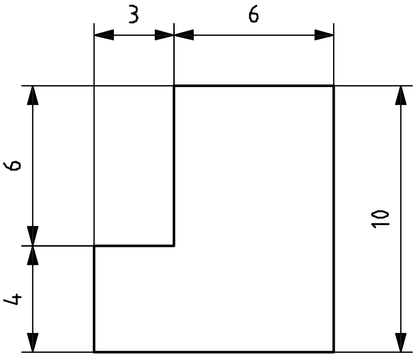


Figure K.2 — L-shaped building

K.2.2 No insulation of floor (thermal resistance of slab neglected).

$d_t = 0{,}3 + 2{,}0\ (0{,}17 + 0 + 0{,}04) = 0{,}72$ m

$$U = \frac{2 \times 2{,}0}{3{,}142 \times 3{,}789 + 0{,}72} \ln\left(\frac{3{,}142 \times 3{,}789}{0{,}72} + 1\right) = 0{,}91\ \mathrm{W/(m^2 \cdot K)}$$

K.2.3 Low density foundations

The foundations are 300 mm thick and 600 mm deep, with thermal conductivity 0,25 W/(m·K). This situation is assessed using the procedure for vertical edge insulation.

For the foundations:

$$R' = \frac{0{,}3}{0{,}25} - \frac{0{,}3}{2{,}0} = 1{,}05\ \mathrm{m^2\ K/W};$$

$$d' = R' \cdot \lambda = 1{,}05 \times 2{,}0 = 2{,}1\ \mathrm{m};$$

$$D = 0{,}6\ \mathrm{m};$$

$$\Psi_g = -\frac{2{,}0}{3{,}142}\left[\ln(2{,}667) - \ln(1{,}426)\right] = -0{,}400\ \mathrm{W/(m \cdot K)};$$

$$U = 0{,}91 - 2 \times 0{,}400/3{,}789 = 0{,}70\ \mathrm{W/(m^2 \cdot K)}.$$

K.2.4 All-over insulation layer

The floor construction incorporates 25 mm of insulation of thermal conductivity 0,04 W/(m·K).

$R_f = 0{,}025/0{,}04 = 0{,}625\ \mathrm{m^2\ K/W}$.

$d_t = 0{,}3 + 2{,}0\ (0{,}17 + 0{,}625 + 0{,}04) = 1{,}97$ m

$$U = \frac{2 \times 2{,}0}{3{,}142 \times 3{,}789 + 1{,}97} \ln\left(\frac{3{,}142 \times 3{,}789}{1{,}97} + 1\right) = 0{,}56\ \mathrm{W/(m^2 \cdot K)}$$

K.2.5 Insulation of high thermal resistance

The floor construction incorporates 100 mm of insulation of thermal conductivity 0,04 W/(m·K).

$$R_f = 0{,}1/0{,}04 = 2{,}5 \text{ m}^2\cdot\text{K/W}$$

$$d_t = 0{,}3 + 2{,}0(0{,}17 + 2{,}5 + 0{,}04) = 5{,}72 \text{ m};$$

$$U = \frac{2{,}0}{0{,}457 \times 3{,}789 + 5{,}72} = 0{,}27 \text{ W/(m}^2 \cdot \text{K)}.$$

K.2.6 Previous example with edge insulation (provided primarily for frost protection)

In addition to all-over insulation as in K.2.5, the foundations are protected by vertical edge insulation against the inner surface of the foundations to a depth of 500 mm and continued beneath the foundations to form ground insulation extending 600 mm from the building (see Figure K.3). Both the vertical and the ground insulation are 75 mm thick with design thermal conductivity of 0,05 W/(m·K), giving thermal resistance of 1,5 m^2·K/W. Additional insulation is provided at corners for frost protection, but this is ignored for the calculation of heat losses.

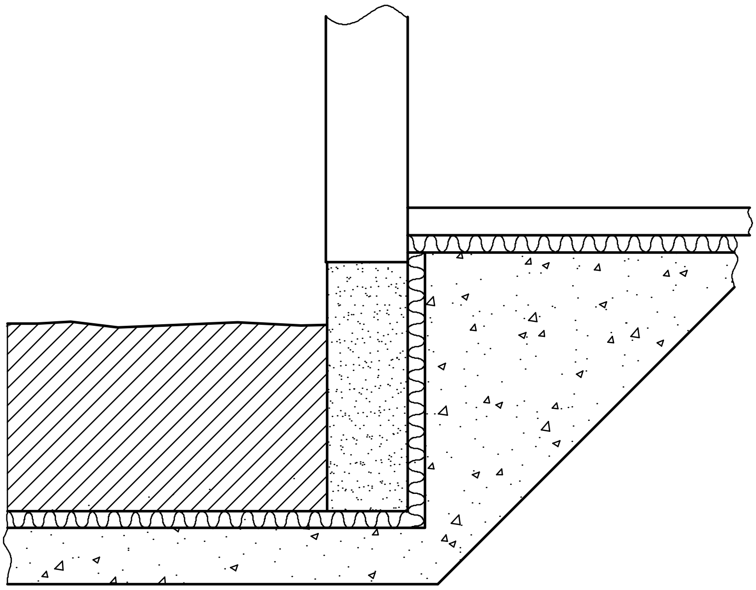


Figure K.3 — Edge insulation for frost protection

Following Annex B, the edge term $\Psi_{g,e}$ is calculated first for the vertical edge insulation and then for the ground insulation, to determine which gives the greater reduction in heat loss.

The additional thermal resistance for the edge insulation is:

$$R' = 1{,}5 - 0{,}075/2{,}0 = 1{,}46 \text{ m}^2 \text{ K/W}$$

so that the additional equivalent thickness is:

$$d' = 1{,}46 \times 2{,}0 = 2{,}92 \text{ m}$$

For the vertical insulation:

$$\Psi_g = -\frac{2{,}0}{3{,}142}\left[\ln\left(\frac{2\times 0{,}5}{5{,}72}+1\right) - \ln\left(\frac{2\times 0{,}5}{5{,}72+2{,}92}\right)+1\right] = -0{,}033 \text{ W/(m}\cdot\text{K)}$$

For the ground insulation:

$$\Psi_{\text{g}} = -\frac{2,0}{3,142}\left[\ln\left(\frac{0,6}{5,72}+1\right)-\ln\left(\frac{0,6}{5,72+2,92}\right)+1\right] = -0,021\ \text{W/(m}\cdot\text{K)}$$

Ψ_{g} for the vertical insulation provides the larger effect so that:

$U = 0,27 - 2 \times 0,033/3,789 = 0,25\ \text{W/(m}^2\cdot\text{K)}$

K.2.7 Thermal bridge at floor edge

Floor insulation is as in K.2.5 but below the slab, so that there is a thermal bridge via the edge of the slab (see Figure K.4). A two-dimensional numerical calculation is used to determine the linear thermal transmittance.

As in K.2.5,

$U_0 = 0,27\ \text{W/(m}^2\cdot\text{K)}$

The numerical calculation in accordance with ISO 10211 gave

$\Psi_{\text{g}} = +\ 0,07\ \text{W/(m}\cdot\text{K)}$

The rate of heat loss per degree allowing for the thermal bridge is then:

$H_{\text{g}} = 0,27 \times 72 + 0,07 \times 38 = 22,1\ \text{W/K}.$

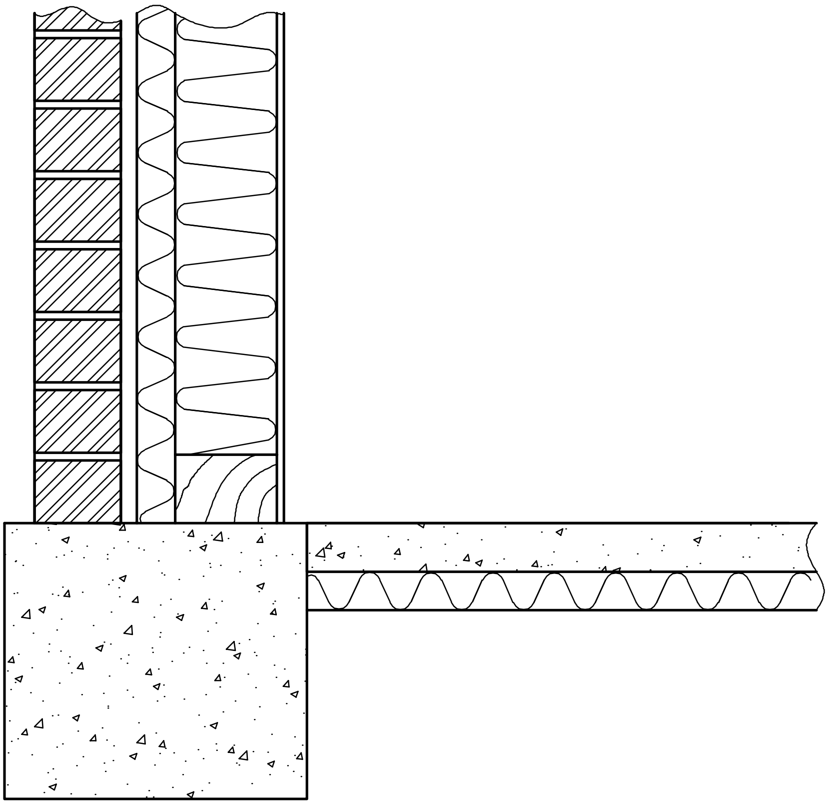


Figure K.4 — Thermal bridge at floor edge

K.3 Example 3: Suspended floor

K.3.1 Definition

Figure K.5 shows a rectangular suspended floor measuring 10,5 m × 7,2 m. The location is of average exposure; the design wind speed is 4,0 m/s; the ventilation openings in the wall of the underfloor space are 0,002 m^2/m; the height of floor above ground level is 0,3 m; the wall thickness is 0,3 m; the soil category is 1.

Dimensions in metres

$P = 35{,}4$ m;

$A = 75{,}6$ m^2;

$B' = 4{,}271$ m.

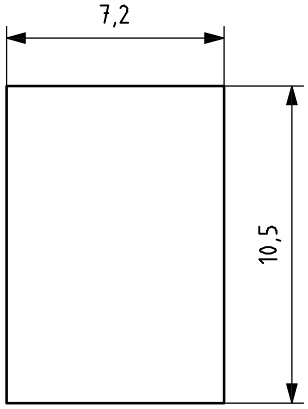


Figure K.5 — Dimensions of suspended floor

K.3.2 Without insulation

The suspended floor is uninsulated [$U_f = 2{,}0$ W/(m^2·K)] and the walls of the underfloor space are uninsulated [$U_w = 1{,}7$ W/(m^2·K)].

U_g is calculated using the total equivalent thickness for the base of the underfloor space (which is uninsulated: $R_g = 0$):

$$d_g = 0{,}3 + 1{,}5(0{,}17 + 0 + 0{,}04) = 0{,}615 \text{ m;}$$

$$U_g = \frac{2 \times 1{,}5}{3{,}142 \times 4{,}271 + 0{,}615} \ln\left(\frac{3{,}142 \times 4{,}271}{0{,}615} + 1\right) = 0{,}668 \text{ W/(m}^2 \cdot \text{K);}$$

$$U_x = \frac{2 \times 0{,}3 \times 1{,}7}{4{,}271} + \frac{1450 \times 0{,}002 \times 4{,}0 \times 0{,}05}{4{,}271} = 0{,}375 \text{ W/(m}^2 \cdot \text{K).}$$

Thus

$$U = \frac{1}{1/2{,}0 + 1/(0{,}668 + 0{,}373)} = 0{,}69 \text{ W/(m}^2 \cdot \text{K).}$$

K.3.3 Insulation of walls of underfloor space

Walls of underfloor space insulated such that

$$U_w = 0{,}5 \text{ W/(m}^2 \cdot \text{K);}$$

$$U_x = \frac{2 \times 0{,}3 \times 0{,}5}{4{,}271} + 0{,}136 = 0{,}206 \text{ W/(m}^2 \cdot \text{K);}$$

$$U = \frac{1}{1/2{,}0 + 1/(0{,}668 + 0{,}206)} = 0{,}61\ \text{W/(m}^2\cdot\text{K)}.$$

K.3.4 Insulation of suspended floor

Suspended floor insulated such that

$U_\text{f} = 0{,}5$ W/(m^2·K);

$U_\text{x} = 0{,}375$ W/(m^2·K), as in K.3.2;

$$U = \frac{1}{1/0{,}5 + 1/(0{,}668 + 0{,}375)} = 0{,}34\ \text{W/(m}^2\cdot\text{K)}.$$

K.4 Example 4 : Heated basement

The basement has floor area 10 m by 7,5 m, and is of depth 2,5 m below ground level; the soil category is 2; the wall thickness at ground level is 0,3 m; the floor of the basement is not insulated; the basement walls consist of 300 mm of masonry [thermal conductivity 1,7 W/(m·K)] and 50 mm of insulation of thermal conductivity 0,035 W/(m·K).

$P = 35$ m; $A = 75$ m^2; $B = 4{,}286$ m; $z = 2{,}5$ m;

$R_\text{f} = 0$ and $R_\text{w} = 0{,}05/0{,}035 + 0{,}3/1{,}7 = 1{,}605$ m^2 K/W;

$d_\text{t} = 0{,}3 + 2{,}0\ (0{,}17 + 0 + 0{,}04) = 0{,}72$ m;

$d_\text{w} = 2{,}0\ (0{,}13 + 1{,}605 + 0{,}04) = 3{,}550$ m;

$d_\text{t} + 0{,}5\ z = 0{,}66 + 1{,}25 = 1{,}91$.

This is less than B', so

$$U_\text{bf} = \frac{2\times 2{,}0}{3{,}142\times 4{,}286 + 0{,}72 + 1{,}25}\ln\left(\frac{3{,}142\times 4{,}286}{0{,}72+1{,}25}+1\right) = 0{,}533\ \text{W/(m}^2\cdot\text{K)};$$

$$U_\text{bw} = \frac{2\times 2{,}0}{3{,}142\times 2{,}5}\left(1+\frac{0{,}5\times 0{,}72}{0{,}72+2{,}5}\right)\ln\left(\frac{2{,}5}{3{,}550}+1\right) = 0{,}302\ \text{W/(m}^2\cdot\text{K)};$$

$H_\text{g} = AU_\text{bf} + zPU_\text{bw} = 75 \times 0{,}533 + 2{,}5 \times 35 \times 0{,}302 = 66{,}4$ W/K;

$U' = 66{,}4/(75 + 2{,}5 \times 35) = 0{,}41$ W/(m^2·K).

K.5 Example 5 : Monthly heat flow rate

Consider house 1 in Example 1, with insulation of thermal resistance 1,25 m^2·K/W all over the floor. The mean monthly external temperatures are as specified in Table K.1.

Table K.1 — Mean monthly external temperatures

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature °C	1,3	1,8	3,7	7,6	10,3	13,5	15,4	14,2	10,4	7,3	5,9	4,3

Less precise information is available concerning the internal temperature: estimates are 15 °C in January and 19 °C in July.

Annual average temperatures:

- Internal: $\bar{\theta}_\text{i} \approx (15 + 19)/2 = 17{,}0$ °C;
- External: (sum of the above monthly values divided by 12) : $\bar{\theta}_\text{e} = 7{,}98$ °C.

Temperature amplitudes:

- Internal: $\bar{\theta}_\text{i} \approx (19 - 15)/2 = 2{,}0$ K;
- External: $\bar{\theta}_\text{e} = (15{,}4 - 1{,}3)/2 = 7{,}05$ K.

$P = 19$ m; $A = 42$ m^2; $B' = 4{,}421$ m; $\lambda = 1{,}5$ W/(m·K); $d_\text{t} = 2{,}49$ m;

$U_0 = 0{,}345$ W/(m^2·K); $H_\text{g} = 14{,}49$ W/K.

From Table F.1, $\delta = 2{,}2$ m.

$$H_\text{pi} = 42 \times \frac{1{,}5}{2{,}49}\sqrt{\frac{2}{(1 + 2{,}2/2{,}49)^2 + 1}} = 16{,}78 \text{ W/K}$$

$$H_\text{pe} = 0{,}37 \times 19 \times 1{,}5 \times \ln\left(\frac{2{,}2}{2{,}49} + 1\right) = 6{,}68 \text{ W/K}$$

Taking $\tau = 1$, $\alpha = 0$ and $\beta = 1$, the heat flow rate for each month can now be obtained (see Table K.2):

$$\Phi_m = 14{,}49(17{,}0 - 7{,}98) - 16{,}78 \times 2{,}0 \times \cos\left(6{,}284 \times \frac{m-1}{12}\right) + 6{,}68 \times 7{,}05 \times \cos\left(6{,}284 \times \frac{m-2}{12}\right)$$

$$= 131 - 33{,}6\cos\left(6{,}284 \times \frac{m-1}{12}\right) + 47{,}1\cos\left(6{,}284 \times \frac{m-2}{12}\right)$$

Table K.2 — Monthly heat flow rate

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heat flow W	138	149	155	154	148	136	124	113	107	107	114	125

If the heating season is from the beginning of September to the end of May (nine months), the average heat flow rate during this period from the data in Table K.2 is 133 W.

Alternatively, using Equations (A.4) and (A.5), i.e. ignoring the phase difference, the average heat flow rate over the heating season is (see Table K.3):

$$\bar{\Phi} = 14{,}49\ (17{,}0 - 7{,}98) - 0{,}3 \times 16{,}78 \times 2{,}0 + 0{,}3 \times 6{,}68 \times 7{,}05 = 131 - 10 + 14 = 135 \text{ W}.$$

If the internal temperature is constant at 20 °C:

$$\Phi_m = 174 + 47{,}1\cos\left(6{,}284\frac{m-2}{12}\right)$$

Table K.3 — Monthly heat flow rate ignoring phase difference

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Heat flow W	215	221	215	198	174	151	133	127	133	151	174	198

Average heat flow from Table K.3 (September to May) = 187 W.

From Equation (A.4), average heat flow (September to May) = 188 W.

The phase difference has little effect on the average heat flow rate over the heating season.

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