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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

Reference number
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Foreword

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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 13370 was prepared by the European Committee for Standardization (CEN) in collaboration with ISO Technical Committee TC 163, *Thermal insulation*, Subcommittee SC 2, *Calculation methods*, in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

Annexes A to F form an integral part of this International Standard. Annexes G to L are for information only.

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Foreword

The text of EN ISO 13370:1998 has been prepared by Technical Committee CEN/TC 89 "Thermal performance of buildings and building components", the secretariat of which is held by SIS, in collaboration with Technical Committee 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of an identical text or by endorsement, at the latest by April 1999, and conflicting national standards shall be withdrawn at the latest by April 1999.

This standard is one of a series of standards on calculation methods for the design and evaluation of the thermal performance of buildings and building components.

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

Introduction

EN ISO 6946 gives the method of calculation of the thermal transmittance of building elements in contact with the external air; this standard deals with elements in thermal contact with the ground. The division between these two 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 prEN 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 standard, simplified procedures are provided which take account of the 3-dimensional nature of the heat flow and which are suitable for the evaluation of heat transfer coefficients and heat flow rates in most cases.

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.

A detailed assessment of floor losses is obtained from, in addition to the steady-state part, 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. Methods of obtaining these periodic coefficients are also given in this standard, and their application to the calculation of heat flow rates is described in annex B.

Worked examples illustrating the use of the methods in this standard are given in annex L.

1 Scope

This standard gives 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 and suspended floors, at the level of the inside floor surface;
- for basements, at the level of the external ground surface.

It 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; this standard does not apply to shorter periods of time.

2 Normative references

This standard incorporates by dated or 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.

EN ISO 6946	Building components and building elements - Thermal resistance and thermal transmittance - Calculation method (ISO 6946:1996)
EN ISO 7345	Thermal insulation - Physical quantities and definitions (ISO 7345:1987)
EN ISO 10211-1	Thermal bridges - Calculation of heat flows and surface temperatures - Part 1: General calculation methods (ISO 10211-1:1995)
prEN ISO 10211-2	Thermal bridges - Calculation of heat flows and surface temperatures - Part 2: Linear thermal bridges (ISO/DIS 10211-2:1995)
ISO 10456	Building materials and products - Procedures for determining declared and design thermal values

3 Definitions, symbols and units

3.1 Definitions

For the purposes of this standard the definitions in EN ISO 7345 apply, together with the following.

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 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 (of a thermal resistance): Thickness of ground (having the thermal conductivity of the actual ground) which has the same thermal resistance.

3.1.5 steady-state thermal coupling coefficient: Steady-state heat flow divided by temperature difference between internal and external environments.

3.1.6 internal periodic thermal coupling coefficient: Amplitude of periodic heat flow divided by amplitude of internal temperature variation over an annual cycle.

3.1.7 external periodic thermal coupling 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	m²
B'	characteristic dimension of floor	m
D	width or depth of edge insulation	m
L_s	steady-state thermal coupling coefficient	W/K
L_{pi}	internal periodic thermal coupling coefficient	W/K
L_{pe}	external periodic thermal coupling coefficient	W/K

Symbol	Quantity	Unit
P	exposed perimeter of floor	m
Q	quantity of heat	J
R	thermal resistance	m²·K/W
R_f	thermal resistance of floor construction	m²·K/W
R_{ins}	thermal resistance of insulation	m²·K/W
R_{si}	internal surface resistance	m²·K/W
R_{se}	external surface resistance	m²·K/W
T	temperature	K or °C
U	thermal transmittance between internal and external environments	W/(m²·K)
U_o	basic thermal transmittance of slab-on-ground floor	W/(m²·K)
U_{bf}	thermal transmittance of basement floor	W/(m²·K)
U_{bw}	thermal transmittance of basement walls	W/(m²·K)
U'	effective thermal tranmittance for whole basement	W/(m²·K)
d_t	total equivalent thickness - floor	m
d_w	total equivalent thickness - basement wall	m
c	specific heat capacity of unfrozen ground	J/(kg·K)
d'	additional equivalent thickness due to edge insulation	m
h	height of floor surface above outside ground level	m
w	thickness of external walls	m
z	depth of basement floor below ground level	m
δ	periodic penetration depth	m
λ	thermal conductivity of unfrozen ground	W/(m·K)
λ_n	thermal conductivity of insulation	W/(m·K)
ρ	density of unfrozen ground	kg/m³
Φ	heat flow rate	W
Ψ_g	linear thermal transmittance associated with wall/floor junction	W/(m·K)
$\Delta\Psi$	correction term for edge insulation of floor slab	W/(m·K)

4 Thermal properties

4.1 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:

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) otherwise, if the soil type is known or specified, use the values in table 1;

c) otherwise use λ = 2,0 W/(m·K) and ρc = 2,0 x 10^6 J/(m³·K).

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 x 10^6
2	sand or gravel	2,0	2,0 x 10^6
3	homogeneous rock	3,5	2,0 x 10^6

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

4.2 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 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.

4.3 Surface resistances

Use the following values:

- internal, downwards heat flow: R_{si} = 0,17 m²·K/W
- internal, horizontal heat flow: R_{si} = 0,13 m²·K/W
- internal, upwards heat flow: R_{si} = 0,10 m²·K/W
- external, all cases: R_{se} = 0,04 m²·K/W

NOTE - These values are taken from ISO 6946.

R_{si} for downwards heat flow applies both at the top and the bottom of an underfloor space. R_{si} for upwards heat flow applies to floors with an embedded heating system and to cold stores.

5 Internal temperature and climatic data

5.1 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 standard requires:

a) annual mean internal temperature;

b) if variations in internal temperature are 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.

5.2 Climatic data

To calculate heat flow rates this standard requires:

a) annual mean external air temperature;

b) if variations in external temperature are 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.

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 that case R_{se} should be excluded from all formulae.

6 Thermal transmittance and heat flow rate

6.1 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 clauses 8 to 12 for the various types of floor and basement: a summary of the relevant equations is provided in table 2.

If the transmission heat loss coefficient for the ground is required, take this as equal to the steady-state thermal coupling coefficient, L_s.

Table 2 - Selection of equations

<table>
<tr><td>Floor type:</td><td colspan="2">For all floor types obtain B' using equation (1)</td></tr>
<tr><td rowspan="2">Slab-on-ground</td><td rowspan="2">Calculate d_t using (2),
and U_o using (3) or (4)</td><td>No edge insulation: $U = U_o$</td></tr>
<tr><td>Edge insulation: $U = U_o + 2\ \Delta\Psi/B'$
Horizontal edge insulation: d' from (8) and $\Delta\Psi$ from (10)
Vertical edge insulation: d' from (8) and $\Delta\Psi$ from (11)</td></tr>
<tr><td>Suspended</td><td colspan="2">Calculate d_g using (14), U_g using (15), U_x using (16) and finally U using (13)</td></tr>
<tr><td rowspan="2">Basement</td><td rowspan="2">Basement floor:
Calculate d_t using (18)
Calculate U_{bf} using (19) or (20)
Basement walls:
Calculate d_w using (21)
and U_{bw} using (22)</td><td>Heated basement: Calculate U' using (23)</td></tr>
<tr><td>Unheated basement : Calculate U using (25)</td></tr>
</table>

6.2 Thermal bridges at edge of floor

The formulae in this 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).

Typical values of Ψ for slab-on-ground floors are given in table 3. This table may be extended on a national basis to include specific wall/floor details, and for a particular dimension system, provided that these values have been obtained in accordance with annex A. The linear thermal transmittance term associated with basements is small and may be neglected.

NOTE: The linear thermal transmittance depends on the system being used for defining building dimensions: see prEN ISO 13789 *Thermal performance of buildings - Transmission heat loss coefficient - Calculation Method (ISO/DIS 13789:1997)*

Table 3 - Values of linear thermal transmittance for wall/floor junctions for slab-on-ground and suspended floors

Insulation arrangement	Linear thermal transmittance Ψ W/(m·K)
Uninsulated floor, or floor in which floor insulation connects directly to wall insulation	0,0
Wall insulation not directly connected to floor insulation, but overlapped with it by at least 200 mm	0,1
Wall insulation not connected to floor insulation	0,2

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.

The thermal transmittance of elements above the separating plane should be assessed according to EN ISO 6946.

6.3 Calculation of heat flow rate

Heat transfer via the ground can be calculated on an annual basis using thermal transmittances only, 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 B, and formulae for the periodic coefficients in annex C.

6.4 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 thermal coupling coefficient L_s may be multiplied by a factor G_w.

NOTE - Illustrative values of G_w are given in annex H.

6.5 Special cases

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

– Heat flow rates for individual rooms : annex D

– Application to dynamic simulation programs: annex E

NOTE: This standard can also be used for slab-on-ground floors with an embedded heating system (see annex J) and for cold stores (see annex K).

7 Parameters used in the calculations

7.1 Characteristic dimension of floor

To allow for the 3-dimensional nature of heat flow within the ground, the formulae in this 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:

$$B' = \frac{A}{\frac{1}{2} P} \tag{1}$$

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, for example 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 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. Thus:

– 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 (for example 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).

7.2 Equivalent thickness

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

A thermal resistance is represented by its equivalent thickness, which is the thickness of ground that has the same thermal resistance. In this 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 thermal coupling coefficients are related to the ratio of equivalent thickness to characteristic floor dimension, and the periodic thermal coupling coefficients are related to the ratio of equivalent thickness to periodic penetration depth.

8 Slab-on-ground floor: uninsulated or with all-over insulation

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.

NOTE - Both uninsulated and evenly insulated slabs may have horizontal and/or vertical edge insulation: these are treated in clause 9.

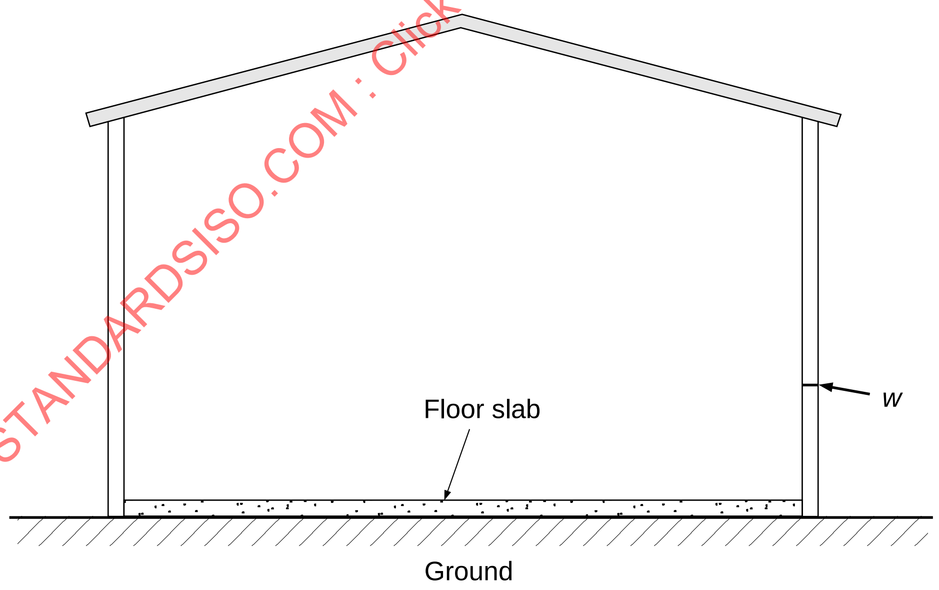

Figure 1 - Schematic diagram of slab-on-ground floor

The thermal transmittance depends on the characteristic dimension of the floor B' (see 7.1 and equation (1)), and the total equivalent thickness d_t (see 7.2) defined as follows:

$$d_t = w + \lambda\,(R_{si} + R_f + R_{se}) \tag{2}$$

where the symbols are defined in 3.2.

w is the full thickness of the walls, including all layers. R_f includes the thermal resistance of any all-over insulation layers above, below or within the floor slab, and that of any floor covering. 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.

To calculate the basic thermal transmittance, U_o, use either (3) or (4), depending on the thermal insulation of the floor.

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

$$U_o = \frac{2\lambda}{\pi B' + d_t} \ln\left(\frac{\pi B'}{d_t} + 1\right) \tag{3}$$

If $d_t \geq B'$ (well-insulated floors):

$$U_o = \frac{\lambda}{0{,}457 B' + d_t} \tag{4}$$

For floors without edge insulation

$$U = U_o \tag{5}$$

and with edge insulation

$$U = U_o + 2\,\Delta\Psi / B' \tag{6}$$

The steady-state thermal coupling coefficient is:

$$L_s = A\,U_o + P\,\Delta\Psi \tag{7}$$

9 Slab-on-ground with edge insulation

9.1 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 clause 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 (see annex A).

First obtain the basic thermal transmittance U_0 according to clause 8 ignoring the edge insulation (but including any all-over insulation). Then obtain the correction term $\Delta\Psi$ according to 9.2 for horizontal edge insulation, or according to 9.3 for vertical edge insulation. The thermal transmittance of the floor is given by equation (6) and the steady-state thermal coupling coefficient by equation (7).

Low-density foundations, of thermal conductivity less than that of the soil, are treated as vertical edge insulation.

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

NOTE - The formulae given below 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.

The equations (10) and (11) include the additional equivalent thickness resulting from the edge insulation, d':

$$d' = R' \lambda \tag{8}$$

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

$$R' = R_n - d_n/\lambda \tag{9}$$

where:

R_n is the thermal resistance of the horizontal or vertical edge insulation (or foundation), in m²·K/W;

d_n is the thickness of the edge insulation (or foundation), in m.

9.2 Horizontal edge insulation

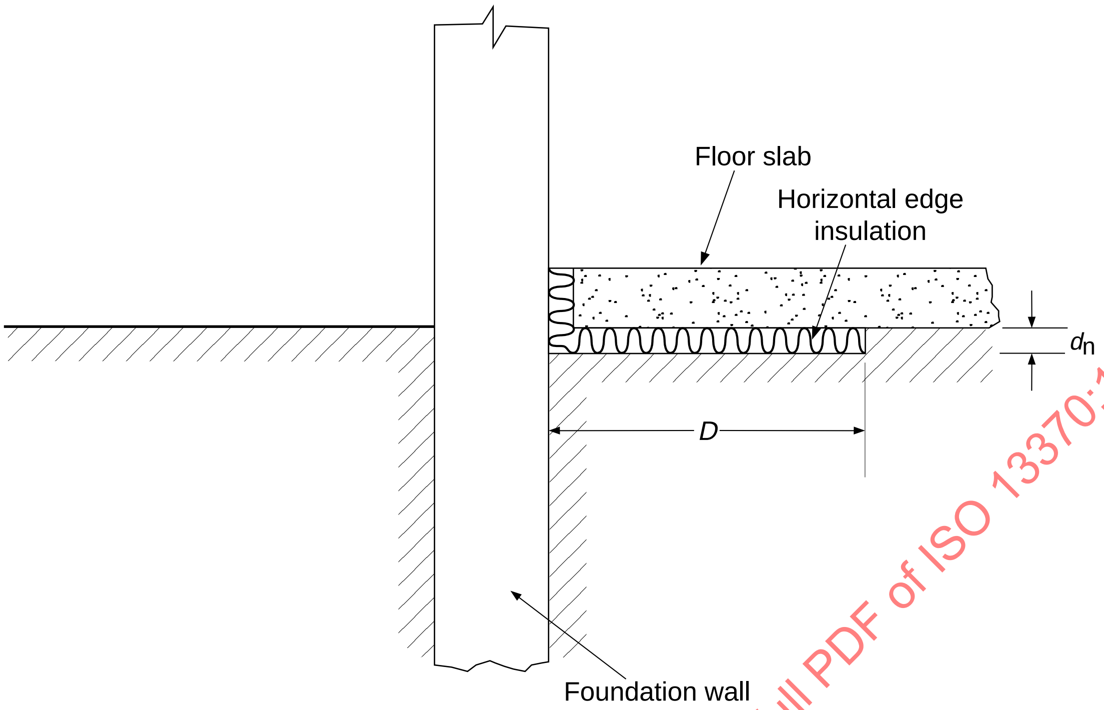

Figure 2 - Schematic diagram of horizontal edge insulation

Equation (10) applies to insulation placed horizontally along the perimeter of the floor (see figure 2).

$$\Delta\Psi = -\frac{\lambda}{\pi}\left[\ln\left(\frac{D}{d_t}+1\right)-\ln\left(\frac{D}{d_t+d'}+1\right)\right] \quad (10)$$

where D is the width of horizontal edge insulation (in m) and d_t is as defined in 9.1.

Figure 2 shows edge insulation below the slab. Equation (10) also applies to horizontal edge insulation above the slab or external to the building.

9.3 Vertical edge insulation

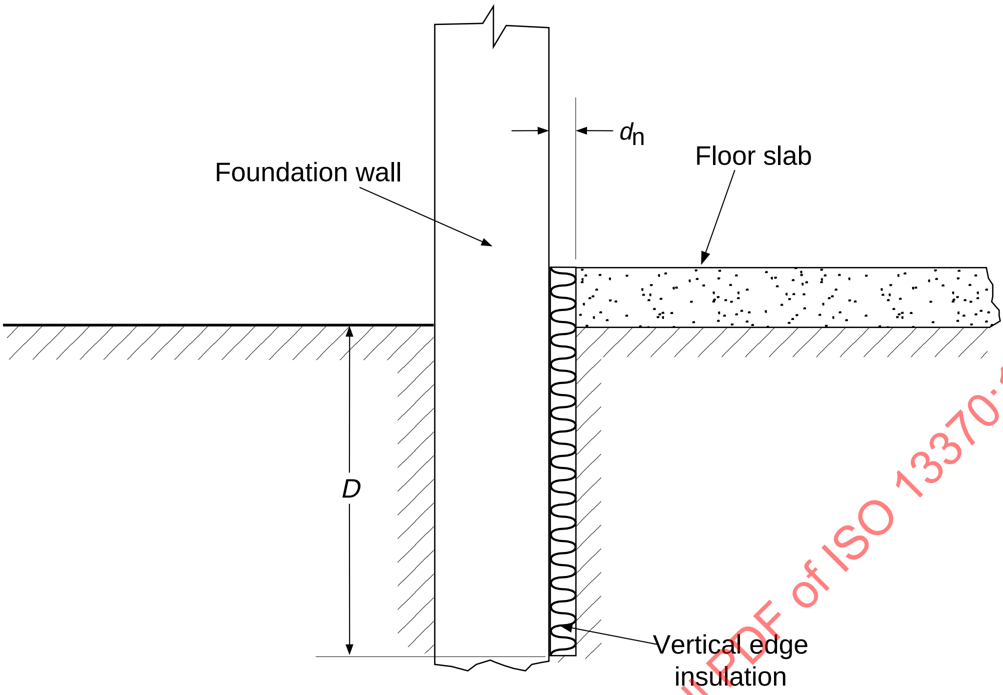

Figure 3 - Vertical edge insulation (insulation layer)

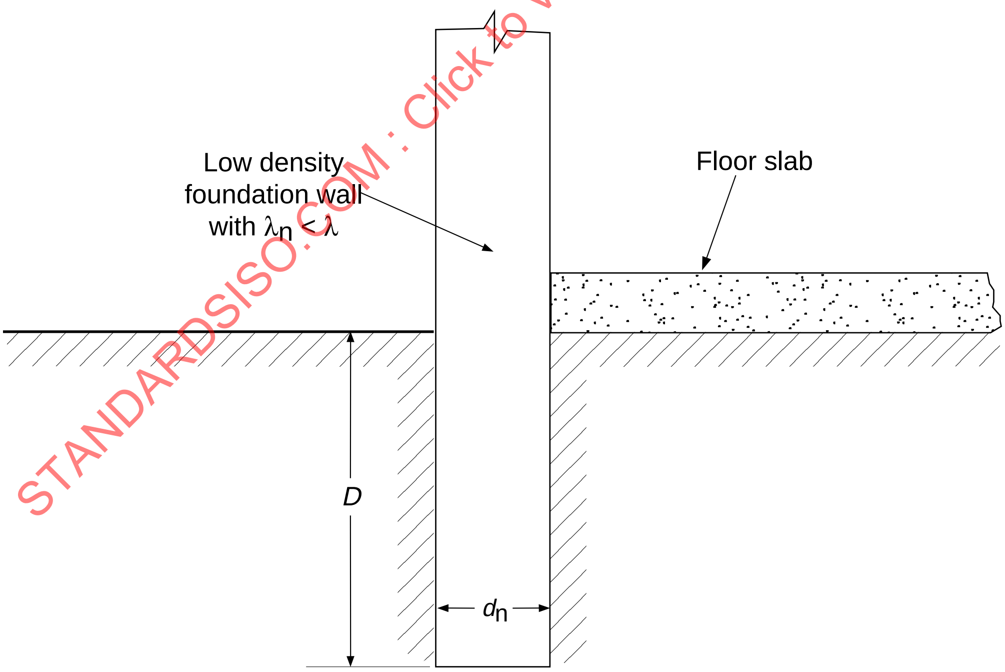

Figure 4 - Vertical edge insulation (low density foundation)

Equation (11) applies to insulation placed vertically below ground along the perimeter of the floor (see figure 3), and to foundations of material of lower thermal conductivity than the ground (see figure 4):

$$\Delta\Psi = -\frac{\lambda}{\pi}\left[\ln\left(\frac{2D}{d_t}+1\right)-\ln\left(\frac{2D}{d_t+d'}+1\right)\right] \quad (11)$$

where D is the depth of vertical edge insulation (or foundation) below ground level (in metres) and d_t is as defined in clause 8.

Figure 3 shows edge insulation inside the foundation wall. Equation (11) also applies to vertical edge insulation outside or within the foundation wall.

10 Suspended floor

A suspended floor is any type of floor held off the ground, for example timber or beam-and-block (see figure 5). 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 F.

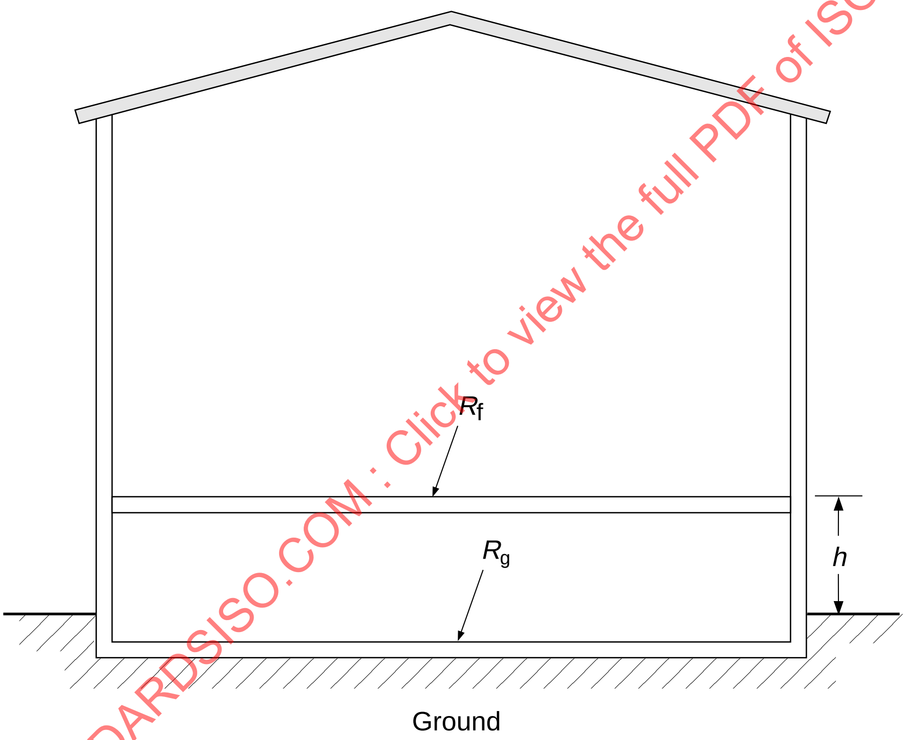

Figure 5 - Schematic diagram of suspended floor

The steady-state thermal coupling coefficient between internal and external environments is

$$L_s = A\,U \quad (12)$$

and the thermal transmittance is given by

$$\frac{1}{U} = \frac{1}{U_f} + \frac{1}{U_g + U_x} \tag{13}$$

where:

U_f is the thermal transmittance of suspended part of floor, in W/(m²·K) (between the internal environment and the underfloor space);

U_g is the thermal transmittance for heat flow through the ground, in W/(m²·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/(m²·K).

Calculate U_f according to EN ISO 6946 using the surface resistance values given in 4.3.

Calculate U_g by means of equations (1), (14) and (15):

$$d_g = w + \lambda\,(R_{si} + R_g + R_{se}) \tag{14}$$

$$U_g = \frac{2\lambda}{\pi B' + d_g} \ln\left(\frac{\pi B'}{d_g} + 1\right) \tag{15}$$

where R_g is the thermal resistance of any insulation on the base of the underfloor space, in m²·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 (F.2) in annex F.

Obtain U_x from:

$$U_x = 2hU_w / B' + 1450\varepsilon v f_w / B' \tag{16}$$

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/(m²·K), calculated according to EN ISO 6946;

ε is the area of ventilation openings per perimeter length of underfloor space, in m²/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 (16).

Annex F 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 4.

Table 4 - Values of the wind shielding factor f_w

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

11 Heated basement

The procedures given for basements apply to buildings in which part of the habitable space is below ground level (see figure 6). 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 of clause 8 for the slab-on-ground.

This standard does not directly cover the case of a building having a floor on the ground for part of it and a basement for part of it. 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.

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. The parts of the walls above ground level should be assessed by their thermal transmittance calculated according to EN ISO 6946.

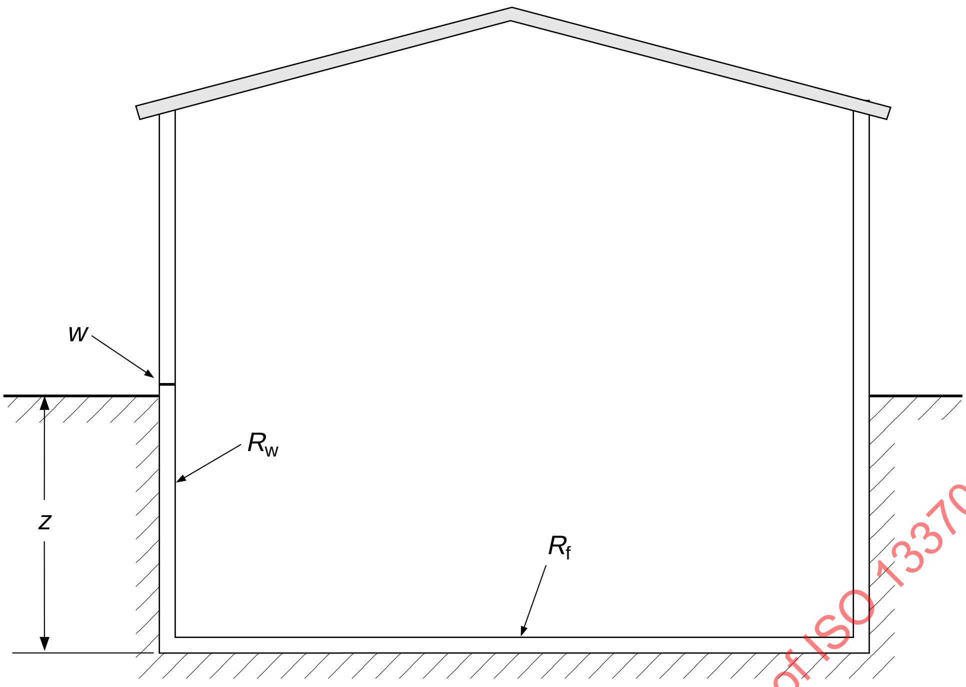

Figure 6 - Schematic diagram of building with heated basement

The steady-state thermal coupling coefficient L_s is given by:

$$L_s = A\,U_{bf} + z\,P\,U_{bw} \qquad (17)$$

NOTE 2 - Equation (17) 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 two terms in (17), for the heat flow through the floor and walls respectively, are approximations.

To determine U_{bf}, calculate the characteristic dimension for the basement floor using equation (1), and include any insulation of the basement floor in the total equivalent thickness:

$$d_t = w + \lambda\,(R_{si} + R_f + R_{se}) \qquad (18)$$

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.

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 (19) or (20), depending on the thermal insulation of the basement floor.

If $(d_t + ½z) < B'$ (uninsulated and moderately insulated basement floors):

$$U_{bf} = \frac{2\lambda}{\pi B' + d_t + ½z} \ln\left(\frac{\pi B'}{d_t + ½z} + 1\right) \quad (19)$$

If $(d_t + ½z) \geq B'$ (well-insulated basement floors):

$$U_{bf} = \frac{\lambda}{0{,}457B' + d_t + ½z} \quad (20)$$

U_{bw} depends on total equivalent thickness for the basement walls:

$$d_w = \lambda\,(R_{si} + R_w + R_{se}) \quad (21)$$

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

Obtain U_{bw} from:

$$U_{bw} = \frac{2\lambda}{\pi z}\left(1 + \frac{0{,}5d_t}{d_t + z}\right) \ln\left(\frac{z}{d_w} + 1\right) \quad (22)$$

The formula for U_{bw} involves both d_w and d_t. It is valid for $d_w \geq d_t$, which is usually the case. If, however, $d_w < d_t$ then d_t should be replaced by d_w in (22).

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

$$U' = \frac{A U_{bf} + zP\,U_{bw}}{A + zP} \quad (23)$$

12 Unheated or partly heated basement

12.1 Unheated basement

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

The steady-state thermal coupling coefficient between the internal and external environments is given by:

$$L_s = A\,U \quad (24)$$

The thermal transmittance U is given by

$$\frac{1}{U} = \frac{1}{U_f} + \frac{A}{A U_{bf} + zP\,U_{bw} + hP\,U_w + 0{,}33nV} \quad (25)$$

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 according to ISO 6946 using the surface resistance values given in 4.3.

Calculate U_{bf} and U_{bw} according to clause 11.

NOTE - The average temperature in the basement may be calculated by the method in annex F.

12.2 Partly heated basement

The heat flow rates for partly heated basements may be calculated as follows:

1) Calculate the heat flow rate for a fully heated basement;

2) Calculate the heat flow rate for an unheated basement;

3) Combine the heat flow rates in 1) and 2) in proportion to the areas of heated and unheated parts of the basement respectively in contact with the ground to obtain the heat flow rate for a partly heated basement.

Annex A (normative)

Numerical calculations

Numerical methods which conform with A.1 and EN ISO 10211-1 or prEN ISO 10211-2 may be used as an alternative to, or in conjunction with, the methods given in this standard for the calculation of the heat transfer from a building via the ground, via:

a) a three-dimensional numerical calculation, giving the result directly for the floor concerned;

b) a two-dimensional numerical calculation, using the characteristic dimension as the floor width, also giving the total heat flow for that floor;

c) a two-dimensional calculation giving the linear thermal transmittance Ψ_g associated with the floor junction and/or the factor $\Delta\Psi$ for edge insulation, and using these in conjunction with the formulae in the standard for any size of floor.

NOTE - Usually the largest heat flows 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 (area divided by half perimeter).

A.1 Conditions for numerical calculations

A.1.1 Subdivision of the geometrical model

The geometrical model of the ground is sub-divided in such a way that the sub-divisions are smallest near to the edge of the floor, and gradually increasing in size to much larger sub-divisions near the truncation planes. EN ISO 10211-1 gives criteria for judging whether sufficient sub-divisions have been used.

A.1.2 Dimensions of the ground

The following minimum dimensions of the ground define the truncation planes in the geomerical model:

- in the horizontal direction inside the building: 0,5 B',
- in the horizontal direction outside the building: 2,5 B',
- in the vertical direction below ground level: 2,5 B',

where B' is the characteristic dimension of the floor for two-dimensional calculations, or the smaller dimension of the floor for three-dimensional calculations.

A.1.3 Boundary conditions

For two-dimensional calculations there is a vertical symmetry plane in the middle of the floor, which is taken as an adiabatic boundary (so that one half of the building is modelled). For three-dimensional calculations on a rectangular building, vertical adiabatic boundaries are taken in the ground mid-way across the floor in each direction (so that one quarter of the building is modelled). For non-rectangular buildings, it is necessary either to model the complete building (together with the ground on all sides), or to convert the problem to a two-dimensional one using a building of width equal to the characteristic dimension of the floor.

Outside the building, the vertical truncation plane is taken as an adiabatic boundary.

The horizontal truncation plane in the ground is taken as an adiabatic boundary.

Surface resistances as specified in 4.3 apply at the inside floor surface and at the outside ground surface.

A.2 Determination of the linear thermal transmittance Ψ for wall/floor junctions

Numerical calculations using a two-dimensional geometrical model can be used to determine values of linear thermal transmittance for wall floor junctions.

First model the full detail, including a section of the wall to height h_w, and calculate L_1^{2D} as the heat flow rate per temperature difference and per perimeter length. h_w should be the minimum distance from the junction to a cut-off plane according to the criteria in prEN ISO 10211-2.

Then replace all material below ground with soil (but retaining any all-over or edge insulation) and remove the wall down to outside ground level (see figure A.2). Use adiabatic boundaries where the wall was previously in contact with the floor slab or the ground. Obtain L_2^{2D} by a second numerical calculation on the revised detail.

Then

$$\Psi = \left(L_1^{2D} - h_w U_w\right) - L_2^{2D}$$

where Uw is the thermal transmittance of the wall above ground, as modelled in the first calculation.

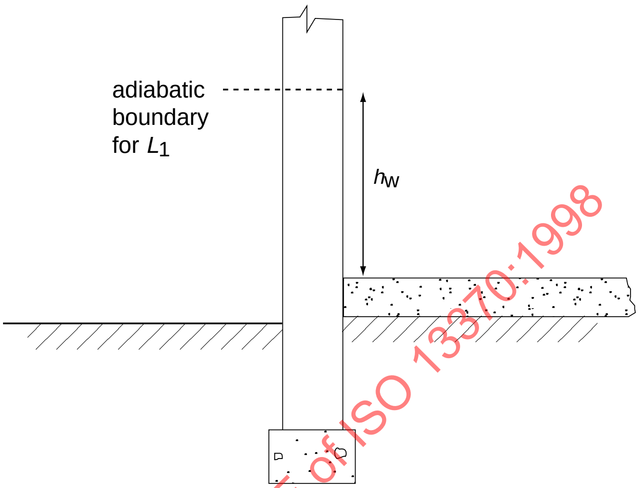

Figure A.1: Schematic diagram for calculation of L_1^{2D}

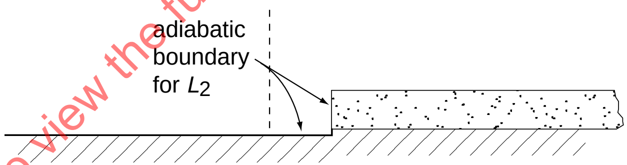

Figure A.2: Schematic diagram for calculation of L_2^{2D}

A.3 Determination of the correction term ΔΨ for edge insulation

Numerical calculations using a two-dimensional geometrical model can be used to determine correction terms ΔΨ.

First undertake the second calculation described in A.2, giving L_2^{2D}.

Then replace the edge insulation with soil and obtain L_3^{2D} by a further numerical calculation.

Then

$$\Delta\Psi = L_3^{2D} - L_2^{2D}$$

A.4 Periodic heat flows

Similar criteria to the foregoing apply to time-dependent numerical calculations for the determination of periodic thermal coupling coefficients, except that adiabatic truncation planes may be taken at positions equal to twice the periodic penetration depth measured from the edge of the floor in any direction (if these dimensions are less than those specified in A.1).

Annex B (normative)

Calculation of ground heat flow rate

Three methods of calculating the heat flow rate are provided, to be chosen by the user having regard to the purpose of the calculation and 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 B.1);

b) calculation of the average ground heat flow rate during the heating season (see B.2);

c) calculation of the annual average ground heat flow rate (see B.3).

B.1 Monthly heat flow rate

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.

For the purposes of calculations according to this standard, the internal and external temperatures are assumed to vary sinusoidally about their annual average values in the following form:

$$T_{i,m} = \overline{T}_i - \hat{T}_i \cos\left(2\pi \frac{m-\tau}{12}\right) \tag{B.1}$$

$$T_{e,m} = \overline{T}_e - \hat{T}_e \cos\left(2\pi \frac{m-\tau}{12}\right) \tag{B.2}$$

where:

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

$\overline{T}_i$ is the annual average internal temperature, in °C;

$\hat{T}_i$ is the amplitude of variations in monthly mean internal temperature, in K, as defined in 5.1;

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

$\overline{T}_e$ is the annual average external temperature, in °C;

$\hat{T}_e$ is the amplitude of variations in monthly mean external temperature, in K, as defined in 5.2;

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.

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 τ = 1 in the Northern Hemisphere and τ = 7 in the Southern Hemisphere.

NOTE 1: τ = 1 assumes the minimum temperature occurs in the middle of January and the maximum temperature in the middle of July, and τ = 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 may be derived from monthly values.

Figure B.1 illustrates the definitions of $\overline{T}_e$ and $\hat{T}_e$. The same applies to the internal temperature.

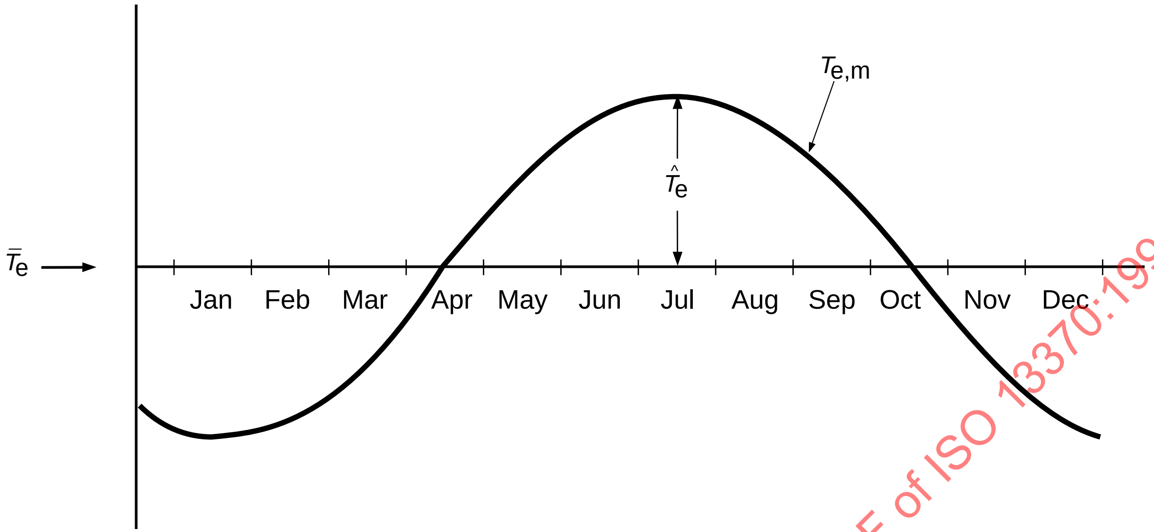

Figure B.1 - Illustration of the variation of external temperature over a year (in Northern hemisphere)

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

$$\Phi_m = L_s(\overline{T}_i - \overline{T}_e) - L_{pi}\hat{T}_i \cos\left(2\pi\frac{m-\tau+\alpha}{12}\right) + L_{pe}\hat{T}_e \cos\left(2\pi\frac{m-\tau-\beta}{12}\right) \quad \text{(B.3)}$$

where:

L_s is the steady-state thermal coupling coefficient, in W/K;

L_{pi} is the internal periodic thermal coupling coefficient, in W/K;

L_{pe} is the external periodic thermal coupling coefficient, in W/K;

α, β are phase differences, in months.

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;

NOTE 3: The periodic heat flow cycle leads the internal temperature variation and lags the external temperature variation. In this standard α and β are both positive numbers: the lead/lag is taken into account in the way equation (B.3) is written.

Methods of calculation of the coefficients L_s, L_{pi} and L_{pe}, and appropriate values of the phase differences α and β, are given in annex C for the different types of floor.

Equation (B.3) assumes that the annual variation of internal temperature is such that T_i is lower in winter than in summer. If the reverse applies, the sign of $\hat{T}_i$ should be taken as negative.

NOTE 4: For calculations based on an assumption of constant internal temperature $\hat{T}_i$ = 0 and L_{pi} need not be considered.

B.2 Average heat flow rate over heating season

For seasonal heat loss 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 (B.3) over the heating season:

$$\overline{\Phi} = L_s\left(\overline{T}_i - \overline{T}_e\right) - \gamma L_{pi}\,\hat{T}_i + \gamma L_{pe}\,\hat{T}_e \qquad \text{(B.4)}$$

where the value of γ, which depends on the length of the heating season, is given by equation (B.5):

$$\gamma = \frac{12}{n\pi}\sin\left(\frac{n\pi}{12}\right) \qquad \text{(B.5)}$$

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

Equation (B.4) assumes that the annual variation of internal temperature is such that T_i is lower in winter than in summer. If the reverse applies, the sign of $\hat{T}_i$ should be taken as negative.

NOTE - For calculations based on an assumption of constant internal temperature $\hat{T}_i$ = 0 and L_{pi} need not be considered.

The use of equation (B.4) is appropriate for heat loss calculations made on a seasonal, rather than a monthly, basis.

Equation (B.4) 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.

B.3 Annual average heat flow rate

If $\hat{T}_i$, $\hat{T}_e$ 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:

$$\Phi_{av} = L_s\left(\overline{T}_i - \overline{T}_e\right) \qquad \text{(B.6)}$$

This is often an adequate approximation, especially if the heating season is long or if $\hat{T}_i$ and $\hat{T}_e$ have opposite effects on the heat flow.

B.4 Maximum monthly heat flow rate

The maximum monthly heat flow rate is given by

$$\Phi_{max} = L_s\left(\overline{T}_i - \overline{T}_e\right) + L_{pe}\,\hat{T}_e \qquad \text{(B.7)}$$

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

B.5 Total heat transfer during heating 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:

$$Q = \sum_{m=m_1}^{m_2} Q_m \qquad \text{(B.8)}$$

$$Q_m = 86\,400\ N_m\ \Phi_m \qquad \text{(B.9)}$$

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 heating season;

m_2 is the last month of heating season;

86 400 is the number of seconds in one day.

In the case of an average heat flow rate from equation (B.4) or equation (B.6):

$$Q = 86\,400\ N\Phi_{av} \qquad \text{(B.10)}$$

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

Annex C (normative)

Periodic thermal coupling coefficients

C.1 Periodic penetration depth

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

$$\delta = \sqrt{\frac{3{,}15 \times 10^7 \lambda}{\pi \rho c}} \qquad (C.1)$$

NOTE: $3{,}15 \times 10^7$ is the number of seconds in a year.

Table C.1 gives approximate values of δ which may be used for calculations by this standard.

Table C.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

C.2 Phase differences

The following equations give approximate values of the phase differences for slab-on-ground floors:

$$\alpha = 1{,}5 - \frac{12}{2\pi}\arctan\left(\frac{d_t}{d_t + \delta}\right) \qquad (C.2)$$

$$\beta = 1{,}5 - 0{,}42\ln\left(\frac{\delta}{d_t + 1}\right) \qquad (C.3)$$

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 (C.2) and (C.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 C.2, which 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 C.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	0	0
Basement (heated or unheated)	0	1

C.3 Slab-on-ground floor: uninsulated or with all-over insulation

C.3.1 Internal temperature variation

The thermal coupling coefficient related to internal temperature variations over an annual cycle is:

$$L_{pi} = A\frac{\lambda}{d_t}\sqrt{\frac{2}{(1+\delta/d_t)^2+1}} \tag{C.4}$$

C.3.2 External temperature variation

The thermal coupling coefficient related to external temperature variations over an annual cycle is:

$$L_{pe} = 0{,}37P\lambda\ln\left(\frac{\delta}{d_t}+1\right) \tag{C.5}$$

C.4 Slab-on-ground with edge insulation

C.4.1 Internal temperature variation

Ignore the edge insulation and calculate L_{pi} according to C.3.1.

C.4.2 External temperature variation

L_{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:

$$L_{pe} = 0{,}37 P \lambda \left[\left(1 - e^{-D/\delta}\right) \ln\left(\frac{\delta}{d_t + d'} + 1\right) + e^{-D/\delta} \ln\left(\frac{\delta}{d_t} + 1\right) \right] \quad \text{(C.6)}$$

where D is the width of horizontal edge insulation (in m) and d' is as defined in clause 9.

For floors incorporating vertical edge insulation:

$$L_{pe} = 0{,}37 P \lambda \left[\left(1 - e^{-2D/\delta}\right) \ln\left(\frac{\delta}{d_t + d'} + 1\right) + e^{-2D/\delta} \ln\left(\frac{\delta}{d_t} + 1\right) \right] \quad \text{(C.7)}$$

where D is the depth of vertical edge insulation (or foundation) below ground level (in m), d_t is as defined in clause 8 and d' is as defined in clause 9.

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

C.5 Suspended floor

In the calculation of the periodic coefficients use U_f, U_x and d_g as defined in clause 10.

C.5.1 Internal temperature variation

$$L_{pi} = A \left[\frac{1}{U_f} + \frac{1}{\lambda/\delta + U_x} \right]^{-1} \quad \text{(C.8)}$$

C.5.2 External temperature variation

$$L_{pe} = U_f \frac{0{,}37 P \lambda \ln\left(\delta / d_g + 1\right) + U_x A}{\lambda/\delta + U_x + U_f} \quad \text{(C.9)}$$

C.6 Heated basement

C.6.1 Internal temperature variation

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

$$L_{pi} = A\frac{\lambda}{d_t}\sqrt{\frac{2}{(1+\delta/d_t)^2+1}} + zP\frac{\lambda}{d_w}\sqrt{\frac{2}{(1+\delta/d_w)^2+1}} \quad \text{(C.10)}$$

C.6.2 External temperature variation

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

$$L_{pe} = 0{,}37P\lambda\left[2\left(1-e^{-z/\delta}\right)\ln\left(\frac{\delta}{d_w}+1\right)+e^{-z/\delta}\ln\left(\frac{\delta}{d_t}+1\right)\right] \quad \text{(C.11)}$$

C.7 Unheated basement

C.7.1 Internal temperature variation

$$L_{pi} = \left[\frac{1}{AU_f}+\frac{1}{(A+zP)\lambda/\delta+hPU_w+0{,}33nV}\right]^{-1} \quad \text{(C.12)}$$

C.7.2 External temperature variation

$$L_{pe} = AU_f\frac{0{,}37P\lambda\left(2-e^{-z/\delta}\right)\ln\left(\delta/d_t+1\right)+hPU_w+0{,}33nV}{(A+zP)\lambda/\delta+hPU_w+0{,}33nV+AU_f} \quad \text{(C.13)}$$

Annex D (normative)

Heat flow rates for individual rooms

The formulae in the 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 total heat flow 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).

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:

$$\Phi_e = \Phi_t \frac{A_e}{A_m \dfrac{b + d_t}{0{,}5B' + d_t} + A_e} \quad \text{(D.1)}$$

$$\Phi_m = \Phi_t - \Phi_e \quad \text{(D.2)}$$

$$q_e = \Phi_e / A_e \quad \text{(D.3)}$$

$$q_m = \Phi_m / A_m \quad \text{(D.4)}$$

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 7.1.

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

Annex E (normative)

Application to dynamic simulation programs

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 ground heat flow rate is treated as consisting of two components. The first component represents the average heat flow rate through the ground, over the period of the calculation: this term is obtained using the methods in this standard. The second component represents the variations in the ground heat flow rate about the average value: this is a dynamic term obtained by solution of the heat diffusion equation with the boundary conditions given below. Thus:

$$\Phi_g = \Phi_f + \Phi_v \quad (E.1)$$

where:

- Φ_g is the time-dependent heat flow rate at floor surface, in W;
- Φ_f is the fixed component of ground heat flow rate, in W;
- Φ_v is the varying component of ground heat flow rate, in W.

Φ_f is pre-calculated and treated as a constant term. It is obtained from equation (B.4), including any insulation of the floor in the determination of the thermal coupling coefficients, for the month number in the middle of the period under consideration (eg m = 7 for July).

NOTE - Values of the annual mean internal temperature and the amplitude of the internal temperature variation can be obtained from an initial estimate of the monthly mean internal temperature in summer, and an estimate of the monthly mean internal temperature in winter related to the use of the building.

Φ_f is the total heat flow over the whole floor area. The heat flux density varies over the area of the floor, but an average value q_f can be used in equations written in terms of the density of heat flow rate:

$$q_f = \Phi_f / A \quad (E.2)$$

Φ_v is obtained using the following assumptions and boundary conditions:

- the dynamic heat flow in the ground is assumed to be one-dimensional;
- the floor construction together with the ground is modelled as a single component consisting of each layer in the floor construction plus 1 m depth of ground;
- an adiabatic boundary is taken in the ground at a depth of 1 m.

Annex F (normative)

Ventilation below suspended floors

F.1 General expressions for average temperature and thermal transmittance

Heat is transferred through the suspended floor to the underfloor space, and then from the underfloor space to the external environment by three mechanisms:

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 mechanisms gives the following as the average temperature of the underfloor space:

$$\overline{T}_{us} = \frac{AU_f\,\overline{T}_i + \dot{V}c_p\rho\,\overline{T}_v + \left(AU_g + hPU_w\right)\overline{T}_e}{AU_f + \dot{V}c_p\rho + AU_g + hPU_w} \tag{F.1}$$

where:

$\overline{T}_{us}$ is the annual average temperature in underfloor space, in K or °C.

$\overline{T}_i$ is the annual average internal temperature, in K or °C;

$\overline{T}_e$ is the annual average external temperature, in K or °C;

$\overline{T}_v$ is the annual average temperature of ventilating air, in K or °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 clause 10 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 analagous to those in clause 11 can be used, so that:

$$U_g = U_{bf} + z\,P\,U_{bw}/A \tag{F.2}$$

with U_{bf} obtained using equation (19) and U_{bw} obtained using equation (22).

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

$$U = U_\mathrm{f} \frac{AU_\mathrm{g} + hPU_\mathrm{w} + \dot{V}c_\mathrm{p}\rho\left(\overline{T}_\mathrm{i} - \overline{T}_\mathrm{v}\right) / \left(\overline{T}_\mathrm{i} - \overline{T}_\mathrm{e}\right)}{AU_\mathrm{f} + AU_\mathrm{g} + hPU_\mathrm{w} + \dot{V}c_\mathrm{p}\rho} \quad \text{(F.3)}$$

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

F.2 Ventilation rate

$\dot{V}$ (m³/s) is specified for mechanically ventilated floors.

For natually ventilated floors:

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

where:

- ε is the area of ventilation opening per perimeter length, in m²/m;
- v is the design wind speed at 10 m height, in m/s;
- f_w is the wind shielding factor defined in clause 10.

For calculations by this standard:

c_p = 1000 J/(kg·K) (at 10°C)

ρ = 1,23 kg/m³ (at 10°C and 100 kPa pressure)

F.3 Natural ventilation

In this case $\overline{T}_\mathrm{v} = \overline{T}_\mathrm{e}$ and re-arrangement of (F.3) together with (F.4) gives equations (13) and (16) of clause 10.

F.4 Mechanical ventilation from inside

In this case $\overline{T}_\mathrm{v} = \overline{T}_\mathrm{i}$ and from (F.3):

$$\frac{1}{U} = \frac{1}{U_\mathrm{f}} + \frac{1 + \dot{V}c_\mathrm{p}\rho / AU_\mathrm{f}}{U_\mathrm{g} + 2hU_\mathrm{w} / B'} \quad \text{(F.5)}$$

F.5 Mechanical ventilation from outside

In this case $\overline{T}_\mathrm{v} = \overline{T}_\mathrm{e}$ and from (F.3):

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

F.6 Unventilated underfloor space

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

$$\frac{1}{U} = \frac{1}{U_f} + \frac{1}{U_g + 2hU_w / B'} \qquad \text{(F.7)}$$

F.7 Unheated basements

Equation (F.6) applies with $\dot{V}c_p\rho = 0{,}33nV$.

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, 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 (eg 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 4.1.

Table G.1 - Thermal conductivity of ground

Ground type	**Dry density** ρ kg/m³	**Moisture content** ***u*** kg/kg	**Degree of saturation** **%**	**Thermal conductivity** λ W/(m·K)	**Representative value of** λ W/(m·K)
silt	1400 to 1800	0,10 to 0,30	70 to 100	1,0 to 2,0	1,5
clay	1200 to 1600	0,20 to 0,40	80 to 100	0,9 to 1,4	
peat	400 to 1100	0,05 to 2,00	0 to 100	0,2 to 0,5	-
dry sand	1700 to 2000	0,04 to 0,12	20 to 60	1,1 to 2,2	2,0
wet sand	1700 to 2100	0,10 to 0,18	85 to 100	1,5 to 2,7	
rock	2000 to 3000	*	*	2,5 to 4,5	3,5

* 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:

$$\rho c = \rho\left(c_s + c_w u\right) \qquad \text{(G.1)}$$

where:

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

ρ is the dry density, in kg/m³;

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 $c_s \approx 1000$ J/(kg·K), and $c_w = 4180$ J/(kg·K) at 10°C.

The representative values of ρc specified in 4.1 were obtained from equation (G.1) as follows (rounding to one significant figure):

clay/silt: $\rho c = 1600 \times (1000 + 4180 \times 0{,}20) = 2{,}94 \times 10^6 \rightarrow 3 \times 10^6$

sand: $\rho c = 1800 \times (1000 + 4180 \times 0{,}05) = 2{,}18 \times 10^6 \rightarrow 2 \times 10^6$

rock: $\rho c = 2500 \times 800 = 2{,}00 \times 10^6 \rightarrow 2 \times 10^6$

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 thermal coupling coefficient, L_s. For suspended floors G_w multiplies the ground thermal transmittance U_g. The factor should not be applied to the periodic thermal coupling coefficients L_{pi} and L_{pe}.

Values of G_w are given in tables H.1, H.2 and H.3 as a function of the dimensionless ratios z_w/B', l/B' and d_t/B', where:

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

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

The length l is given by:

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

where:

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

ρ_w is the density of water, in kg/m³;

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

NOTE 1 - $\rho_w c_w = 4{,}18 \times 10^6$ J/(m³·K) at 10°C.

NOTE 2 - If l >> B' the conduction heat flow predominates and if l << B' the ground water heat flow predominates.