INTERNATIONAL STANDARD

ISO 13370

Second edition
2007-12-15

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
ISO 13370:2007(E)

ISO copyright office
Case postale 56 • CH-1211 Geneva 20
Tel. + 41 22 749 01 11
Fax + 41 22 749 09 47
E-mail copyright@iso.org
Web www.iso.org

Published in Switzerland

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Foreword

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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):

$$H_g = AU + P\Psi_g \qquad (1)$$

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/(m³·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

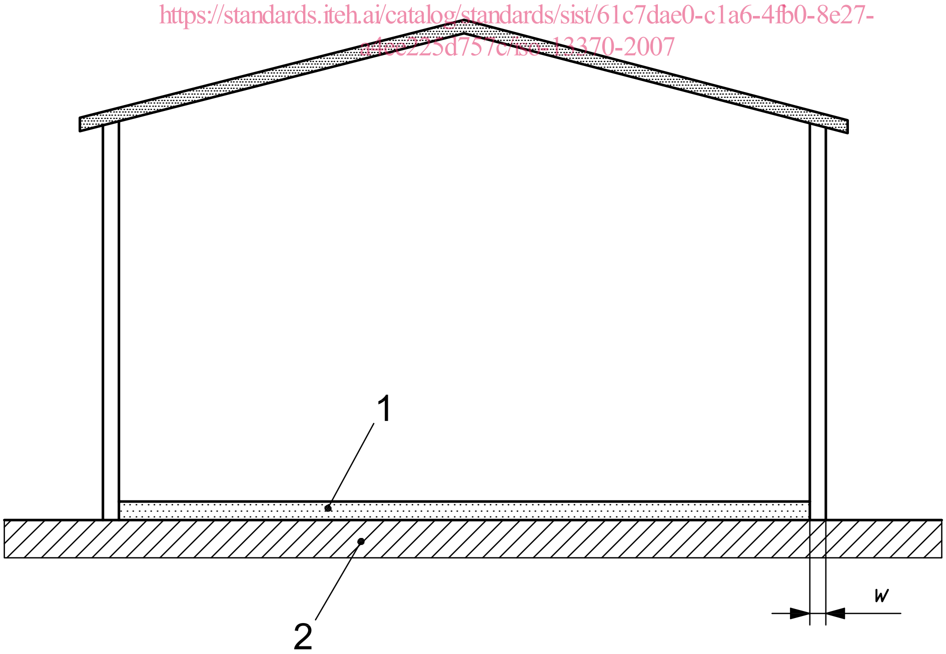
9.1 Slab-on-ground floor

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.