TECHNICAL REPORT

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2017-06

Energy performance of buildings — Hygrothermal performance of building components and building elements —

Part 2: Explanation and justification

Performance énergétique des bâtiments — Performances hygrothermiques des composants et parois de bâtiments —

Partie 2: Explication et justification

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Contents

Foreword

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

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the voluntary nature of standards, the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the World Trade Organization (WTO) principles in the Technical Barriers to Trade (TBT) see the following URL: www.iso.org/iso/foreword.html.

ISO/TR 52019-2 was prepared by ISO Technical Committee ISO/TC 163, *Thermal performance and energy use in the built environment*, Subcommittee SC 2, *Calculation methods*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 89, *Thermal performance of buildings and building components,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

A list of all parts in the ISO 52019 series can be found on the ISO website.

Introduction

The set of EPB standards, technical reports and supporting tools

In order to facilitate the necessary overall consistency and coherence, in terminology, approach, input/output relations and formats, for the whole set of EPB-standards, the following documents and tools are available:

a) a document with basic principles to be followed in drafting EPB-standards: CEN/TS 16628:2014, *Energy Performance of Buildings - Basic Principles for the set of EPB standards*[8];

b) a document with detailed technical rules to be followed in drafting EPB-standards; CEN/TS 16629:2014, *Energy Performance of Buildings - Detailed Technical Rules for the set of EPB-standards*[9].

The detailed technical rules are the basis for the following tools:

1) a common template for each EPB-standard, including specific drafting instructions for the relevant clauses;

2) a common template for each technical report that accompanies an EPB standard or a cluster of EPB standards, including specific drafting instructions for the relevant clauses;

3) a common template for the spreadsheet that accompanies each EPB standard, to demonstrate the correctness of the EPB calculation procedures.

Each EPB-standards follows the basic principles and the detailed technical rules and relates to the overarching EPB-standard, ISO 52000-1[5].

One of the main purposes of the revision of the EPB-standards is to enable that laws and regulations directly refer to the EPB-standards and make compliance with them compulsory. This requires that the set of EPB-standards consists of a systematic, clear, comprehensive and unambiguous set of energy performance procedures. The number of options provided is kept as low as possible, taking into account national and regional differences in climate, culture and building tradition, policy and legal frameworks (subsidiarity principle). For each option, an informative default option is provided (Annex B).

Rationale behind the EPB technical reports

There is a risk that the purpose and limitations of the EPB standards will be misunderstood, unless the background and context to their contents – and the thinking behind them – is explained in some detail to readers of the standards. Consequently, various types of informative contents are recorded and made available for users to properly understand, apply and nationally or regionally implement the EPB standards.

If this explanation would have been attempted in the standards themselves, the result is likely to be confusing and cumbersome, especially if the standards are implemented or referenced in national or regional building codes.

Therefore each EPB standard is accompanied by an informative technical report, like this one, where all informative content is collected, to ensure a clear separation between normative and informative contents (see CEN/TS 16629[9]):

— to avoid flooding and confusing the actual normative part with informative content,

— to reduce the page count of the actual standard, and

— to facilitate understanding of the set of EPB standards.

This was also one of the main recommendations from the European CENSE project[5] that laid the foundation for the preparation of the set of EPB standards.

This document

This technical report accompanies the suite of EPB standards on thermal transmission properties of building elements. It relates to ISO 6946, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683, which form part of a set of standards related to the evaluation of the energy performance of buildings (EPB).

The role and the positioning of the accompanied standards in the set of EPB standards is defined in the introductions to ISO 6946, ISO 10211, ISO 13370, ISO 13786 and ISO 14683.

Accompanying spreadsheets

Concerning ISO 6946, ISO 10211, ISO 13370, ISO 13786 and ISO 14683, spreadsheets were produced for:

— ISO 6946;

— ISO 13370;

— ISO 13789.

These spreadsheets are available at www.epb.center.

In this document, examples of each of these calculation sheets are included in Annex M.

No accompanying calculation spreadsheets were prepared on:

— ISO 10211: this document does not provide a calculation procedure; it provides test cases and performance criteria for calculation procedures.

— ISO 13786: this document provides complex matrix calculation procedures. Instead of a spreadsheet, Annex I contains examples of calculation results obtained by a computer program.

— ISO 14683: this document does not provide a calculation procedure; it provides choices between procedures provided elsewhere and default tabulated values. Instead, Annex L contains examples of the use of default values.

The first series of standards on thermal and hygrothermal properties of building components and elements were prepared by ISO Technical Committee TC 163 in the 1980s, as a result of growing global concern on future fuel shortages and inadequate health and comfort levels in buildings. During the following decades these first standards were revised and new standards were added, to cope with new developments and additional needs. From the 1990s on, these standards were developed in close collaboration with CEN.

Energy performance of buildings — Hygrothermal performance of building components and building elements —

Part 2:
Explanation and justification

1 Scope

This document contains information to support the correct understanding and use of ISO 6946, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683.

This document does not contain any normative provision.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 6946:2017, *Building components and building elements — Thermal resistance and thermal transmittance — Calculation methods*

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

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

ISO 13370:2017, *Thermal performance of buildings — Heat transfer via the ground — Calculation methods*

ISO 13786, *Thermal performance of building components — Dynamic thermal characteristics — Calculation methods*

ISO 13789, *Thermal performance of buildings — Transmission and ventilation heat transfer coefficients — Calculation method*

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

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 6946, ISO 7345, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683 apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— IEC Electropedia: available at http://www.electropedia.org/

— ISO Online browsing platform: available at http://www.iso.org/obp

4 Symbols and subscripts

For the purposes of this document, the symbols and subscripts given in ISO 6946, ISO 7345, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683 apply.

5 Description of the methods

5.1 Outputs

The main outputs of ISO 6946, ISO 7345, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683 are:

— thermal transmission properties of building elements (thermal resistance, thermal transmittance or dynamic thermal characteristics of a wall, floor or roof);

— heat transfer coefficient for the whole building (or part of a building).

5.2 General description

Together with ISO 10456, ISO 10077-1, ISO 10077-2 and ISO 12631, these documents (ISO 6946, ISO 7345, ISO 10211, ISO 13370, ISO 13786, ISO 13789 and ISO 14683) provide the methodology to obtain heat transfer coefficients for a building starting from the properties of materials used for its construction and the size and geometry of the building.

The results provide input for calculation of energy needs for heating and cooling by ISO 52016-1[7] when one of the simplified (monthly or hourly) calculation methods is being used in ISO 52016-1. In the case of detailed dynamic simulations, the component (or subcomponent) properties are used directly as inputs for the building simulation.

In applications where individual component properties are needed, these documents provide:

— in the case of minimum component requirements, the *U*-value or *R*-value of the construction;

— for multi-zone calculations with assumed thermal interaction between the zones, the thermal transmission properties of the separating construction;

Figure 1 illustrates the linkages between these documents.

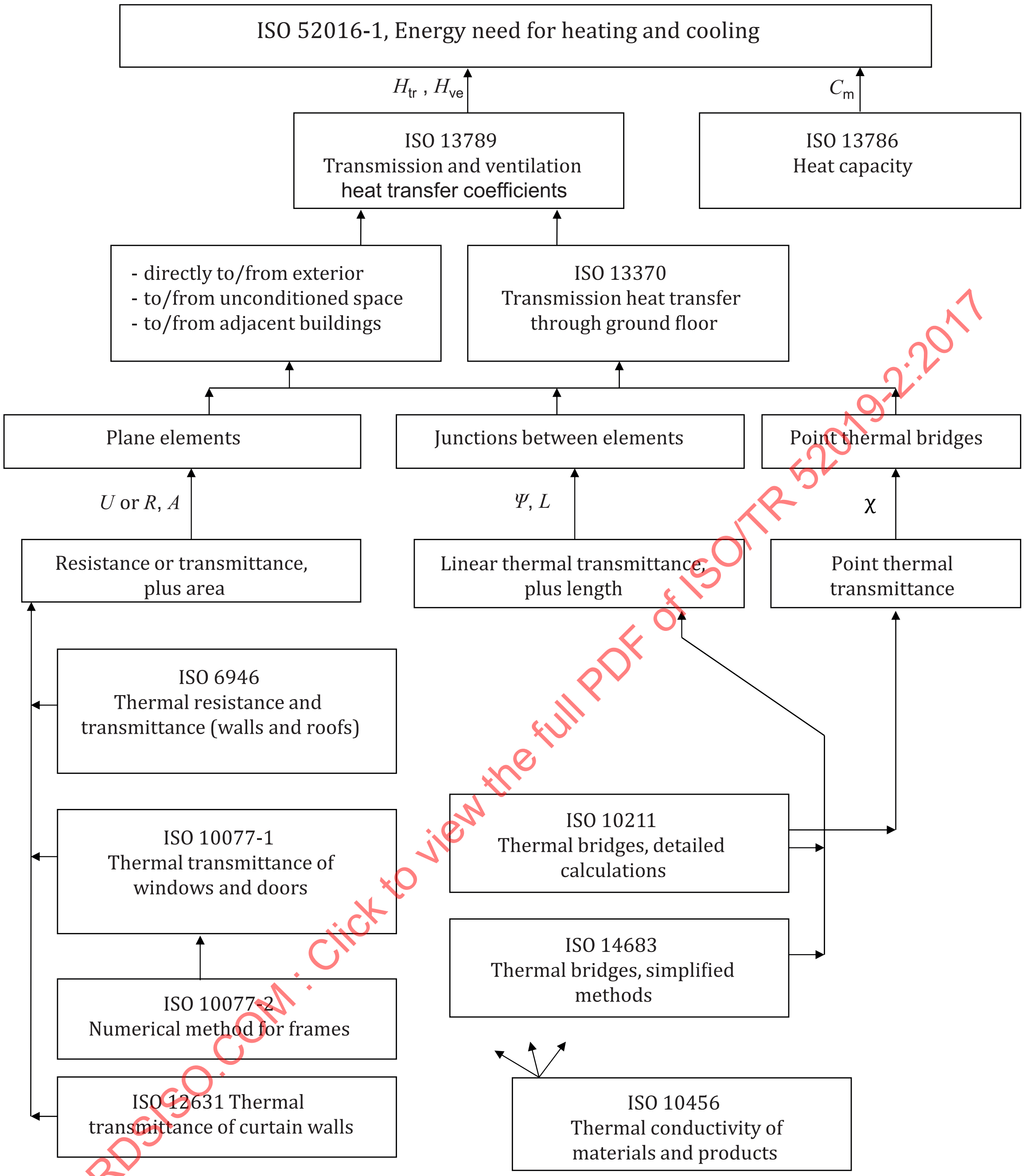


Figure 1 — Linkage between documents

More information can be found in [20] and [21].

6 ISO 6946

ISO 6946 provides a calculation method that is valid for most building components (walls and roofs). It is based on calculating the upper limit of thermal resistance of the component (which would apply if the heat flow were unidirectional from warm side to cold side) and the lower limit (in which the plane separating each layer is isothermal). Except for components consisting entirely of homogeneous layers (for which the upper and lower limits are equal) the true thermal resistance of a component is between these two limits. ISO 6946 specifies use of the arithmetic mean of the two limits provided that their ratio does not exceed 1,5.

7 ISO 10211

ISO 10211 specifies the method for detailed calculation of thermal bridges. It can be applied to a whole building or part of it, and also to the calculation of linear and point thermal transmittances which are used in ISO 13789.

8 ISO 13370

8.1 General

ISO 13370 is used for calculation of heat transfer via the ground, taking account of its contribution to the total thermal resistance in the case of U-value calculations and of its thermal inertia in the case of time-dependent calculations.

The following sub-clauses provide information in addition to that given in ISO 13370.

More background information can be found in references [12]–[19].

8.2 Thermal properties of the ground

ISO 13370 specifies thermal properties for three representative types of ground. Particular values can be provided in ISO 13370:2017, Annex A.

Annex A provides background information on the properties of the ground.

8.3 The influence of flowing ground water

In most cases it is not necessary to take account of ground water since its flow rate is usually sufficiently small that it has a negligible effect on heat transfer rates. Further information and a method of allowing for the effect of ground water when its flow rate is known are given in Annex B.

8.4 Application to dynamic simulation programmes

ISO 13370:2017, Annex F contains a procedure for the application to dynamic simulation programmes.

Annex C provides background information and validation of this procedure.

8.5 Embedded heating or cooling systems

Annex D describes a modification of the methodology in ISO 13370 for floors with an embedded heating or cooling system.

8.6 Cold stores

Annex E provides a method to calculate the heat gain to a cold store from heating elements in the ground (included to avoid frost heave).

9 ISO 13786

ISO 13786 defines a method of calculation of the dynamic thermal characteristics of a building component. Annex G gives background to the matrix method given in ISO 13786.

Annex H provides information on computer programming for complex numbers and Annex I gives the results of some sample calculations.

10 ISO 13789

ISO 13789 defines the calculation of the transmission heat transfer coefficient of a building, using the heat transmission properties of the building elements and thermal bridge used in its construction. A decision is needed on the system of dimensions to be used – internal, overall internal or external. Annex J illustrates the three systems and the effect of the systems on the linear thermal transmittance of junctions between elements. Annex J is relevant also to ISO 10211 and ISO 14683.

For the ventilation heat transfer coefficient the air flow rate through conditioned spaces is needed. Annex K provides a possible method, with associated data.

11 ISO 14683

ISO 14683 defines the methodology for determination of linear thermal transmittances and provides default values for when specific information is not available. Annex L provides examples of the influence of thermal bridges on the transmission heat loss coefficient.

Annex A
(informative)

ISO 13370: Thermal properties of the ground

For the purposes of this annex, the symbols and subscripts given in ISO 13370 apply.

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 A.1 indicates the range of thermal conductivity for various types of unfrozen ground, and shows the representative values specified in ISO 13370.

Table A.1 — Thermal conductivity of ground

Ground type	Dry density ρ kg/m^3	Moisture content u kg/kg	Degree of saturation %	Thermal conductivity λ_g 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, $\rho \cdot c$, can be obtained from Formula (A.1).

$$\rho \cdot c = \rho \cdot \left(c_s + c_w \cdot u \right) \quad \text{(A.1)}$$

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_s approximately 1 000 J/(kg·K), and c_w = 4 180 J/(kg·K) at 10 °C.

The representative values of $\rho \cdot c$ specified in ISO 13370 are obtained from Formula (A.1), as follows (rounding to one significant figure):

— clay/silt: $\rho \cdot c = 1\,600 \times (1\,000 + 4\,180 \times 0{,}20) = 2{,}94 \times 10^6 \rightarrow 3 \times 10^6$

— sand: $\rho \cdot c = 1\,800 \times (1\,000 + 4\,180 \times 0{,}05) = 2{,}18 \times 10^6 \rightarrow 2 \times 10^6$

— rock: $\rho \cdot c = 2\,500 \times 800 = 2{,}00 \times 10^6 \rightarrow 2 \times 10^6$

Annex B
(informative)

ISO 13370: The influence of flowing ground water

For the purposes of this annex, the symbols and subscripts given in ISO 13370 apply.

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 B.1 as a function of the dimensionless ratios $\frac{z_w}{B}$, $\frac{l_c}{B}$ and $\frac{d_f}{B}$, 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;

B Is the characteristic dimension of floor, in m;

d_f Is the total equivalent thickness of the slab on ground floor, in m.

The length l_c is given by Formula (B.1).

$$l_c = \frac{\lambda}{\rho_w c_w q_w} \tag{B.1}$$

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 $\rho_w \cdot c_w = 4{,}18 \times 10^6$, in J/(m3·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 B.1 — Values of G_w

z_w/B	l_c/B	G_w		
		d_f/B = 0,1	d_f/B = 0,5	d_f/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

Table B.1 *(continued)*

z_w/B	l_c/B	G_w		
		$d_f/B = 0,1$	$d_f/B = 0,5$	$d_f/B = 1,0$
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 C
(informative)

ISO 13370: Application to dynamic simulation programmes

C.1 General

For the purposes of this annex, the symbols and subscripts given in ISO 13370 apply.

ISO 13370:2017, Annex F provides 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 interval of one hour or less.

The method involves modelling the floor construction together with the ground 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 has a thermal resistance R_{vi} and has negligible thermal capacity. R_{vi} is calculated from Formula (C.1).

$$R_{vi} = \frac{1}{U} - R_{si} - R_f - R_g \quad (C.1)$$

The boundary condition at the bottom of the virtual layer is a virtual temperature, θ_{vi}, which is calculated for each time interval being applied in the numerical model using Formula (C.2).

$$\theta_{vi,t} = \theta_{int,t} - \frac{\Phi_t}{AU} \quad (C.2)$$

where Φ_t is calculated at time t, using the numerical model.

Using this method, the virtual layer represents the ground in the numerical model, simplifying the model by avoiding the need to include large volumes of ground. The value of R_{vi} is set so as to give the correct annual average heat flow and the effect of transient heat flow in the ground is accounted for by the time-varying virtual temperature.

C.2 Validation

The method has been validated by comparing its results with those of a dynamic numerical model that included explicit modelling of the ground with dimensions as given in ISO 10211[1)].

C.2.1 Geometrical model and thermal transmittance

The geometric model consisted of one-quarter of a square building with the length of each side being 5 m (see Figure C.1).

1) The method was proposed and validated by Physibel, Belgium.

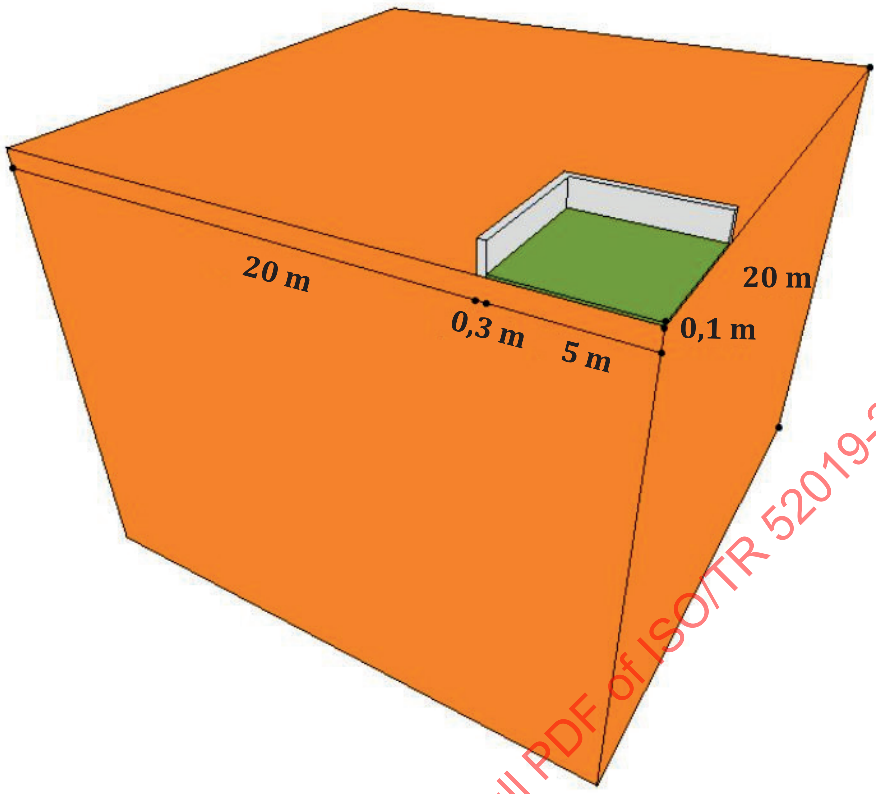


Figure C.1 — Geometrical model including ground dimensions according to ISO 10211

Table C.1 — Input data and results

Input data	Result
Thermal conductivity of ground	λ_g = 2,0 W/(m·K)
Heat capacity of ground	$\rho \cdot c$ = 0,5 × 10^6 J/(m^3·K)
Internal surface heat transfer coefficient	h_{int} = 7,7 W/(m^2·K)
External surface heat transfer coefficient	h_e = 25 W/(m^2·K)
U-value by 3-D simulation model	*U* = 0,427 W/(m^2·K)
Using ISO 13370:2017, Annexes C and F	*U* = 0,423 W/(m^2·K)

C.2.2 Validation simulation for sinusoidal temperature variations

This simulation was done with the floor properties given in Table C.2 and sinusoidal variations of temperature (both inside and outside).

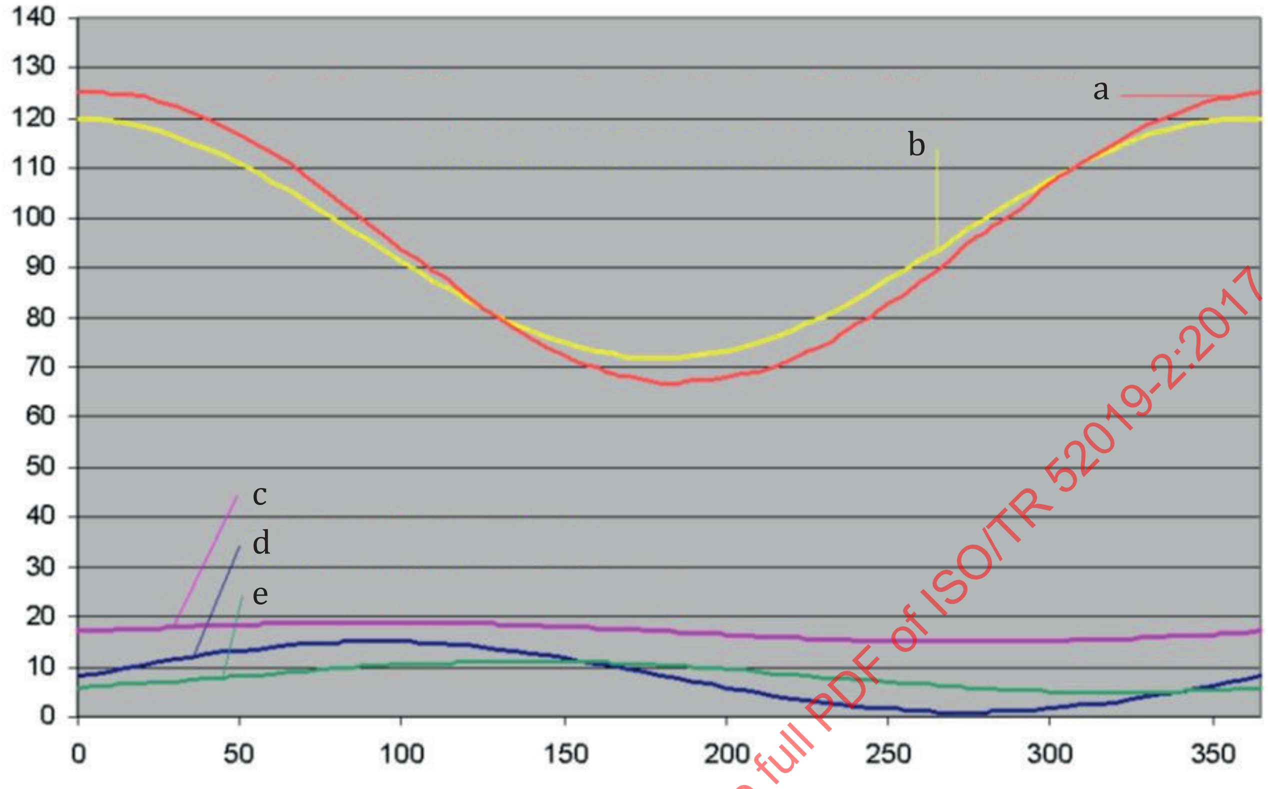
Table C.2 — Floor details

Layer	Thickness d m	Thermal conductivity λ_g W/(m·K)	Density ρ kg/m^3	Specific heat c J/(kg·K)
Screed	0,1	0,1	500	1000
Ground	0,5	2	2000	1000
Virtual layer	0,1	0,108 [a]	1 [b]	1 [b]

[a] Derived from floor U-value of 0,43 W/(m^2·K)

[b] As recommended in ISO 13370:2017, Annex F.

The results in Figure C.2 show good agreement.



Key

a heat loss (W) proposed method using 1D building simulation

b heat loss (W) 3D numerical method

c indoor temperature (°C)

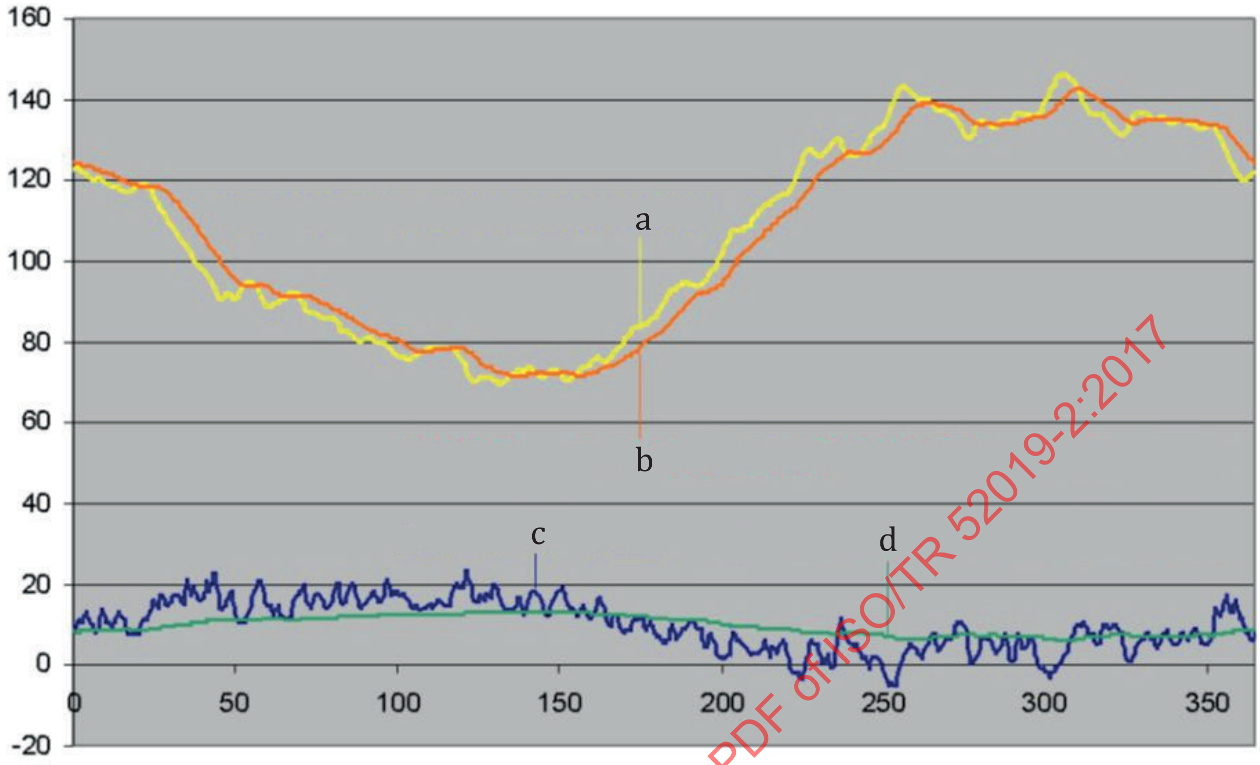
d outdoor temperature (°C)

e virtual ground temperature (°C)

Figure C.2 — Results for sinusoidal temperature variations

C.2.3 Validation simulation for actual external temperature variations

The internal temperature was held constant at 20 °C and the floor defined by Table C.2 was subject to the daily external temperature for Brussels for 1 year starting on 20 April. The results in Figure C.3 show that the method is not limited to sinusoidal variations.



Key

a heat loss (W) 3D numerical method

b heat loss (W) proposed method using 1D building simulation

c outdoor temperature (°C)

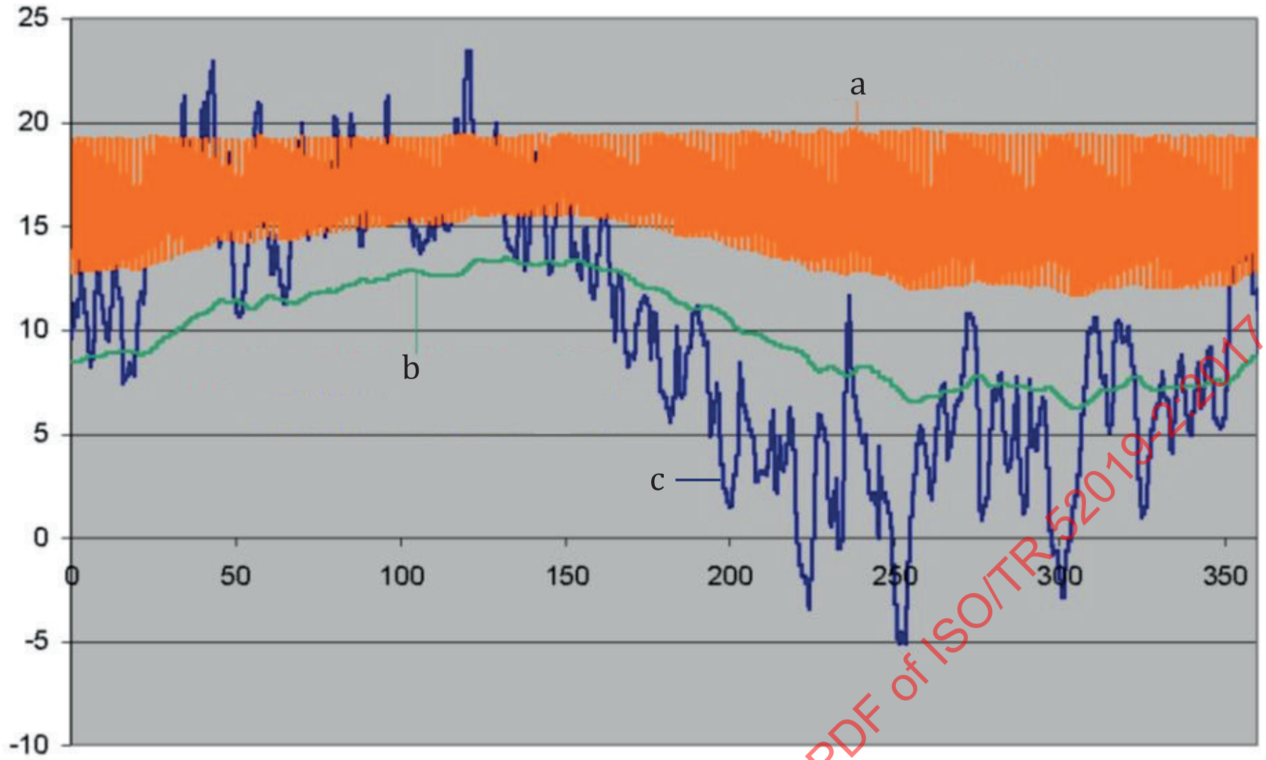
d virtual ground temperature (°C)

Figure C.3 — Results for actual external temperature variations

C.2.4 Validation simulation for calculation of internal temperature

In this case there is a specified heat input and the resulting internal temperature is calculated. A building was used with floor described in Table C.2, all other elements set to adiabatic and having no thermal mass, and with no ventilation (so that all heat transfer is via the floor). The building was heated from 06:00 to 18:00. The power dissipated in the building was a function of the mean external temperature for the day, in order to obtain a more-or-less constant day temperature during the year.

Figure C.4 shows the results. The indoor temperature obtained by the simulations is visible only as a band because of the daily temperature fluctuations. Figure C.5 shows the first six days of the simulations, and contains the indoor temperature obtained by both methods. The differences obtained are small.



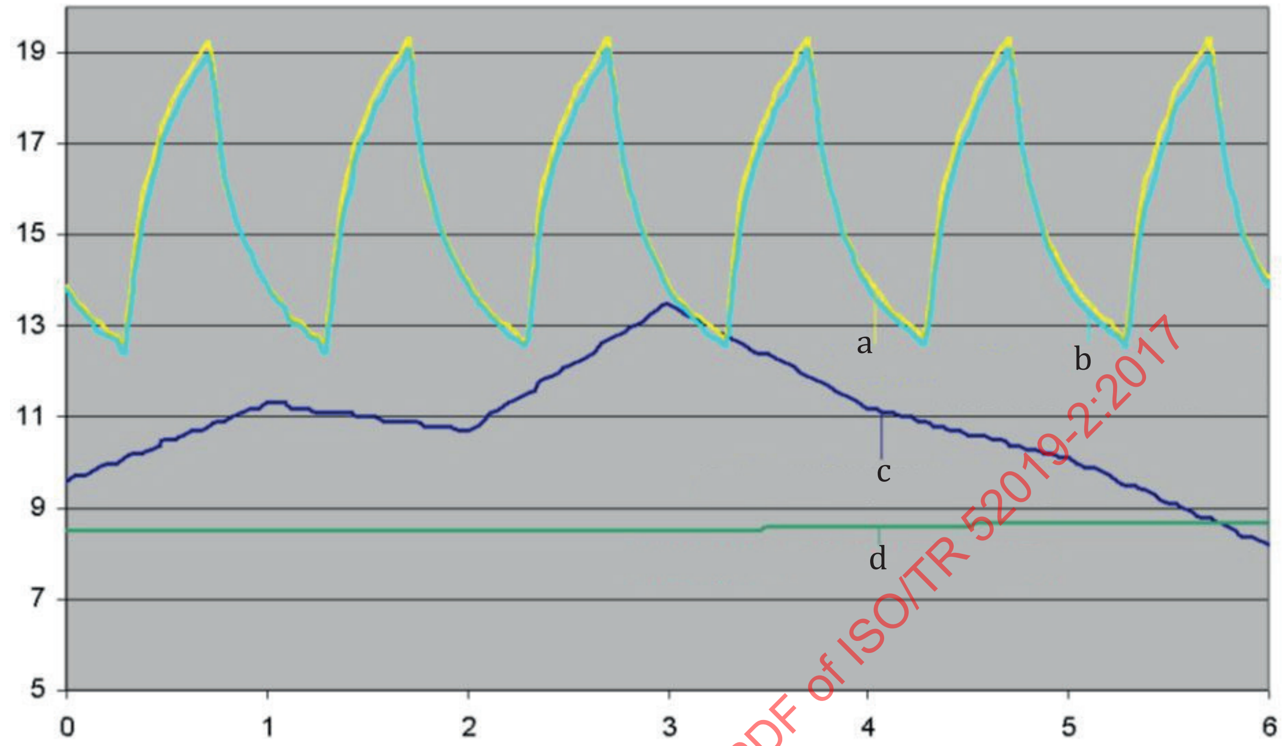
Key

a indoor temperature (°C)

b virtual ground temperature (°C)

c outdoor temperature (°C)

Figure C.4 — Calculated internal temperature for one year



Key

a indoor temperature (°C) 3D simulation

b indoor temperature (°C) 1D simulation

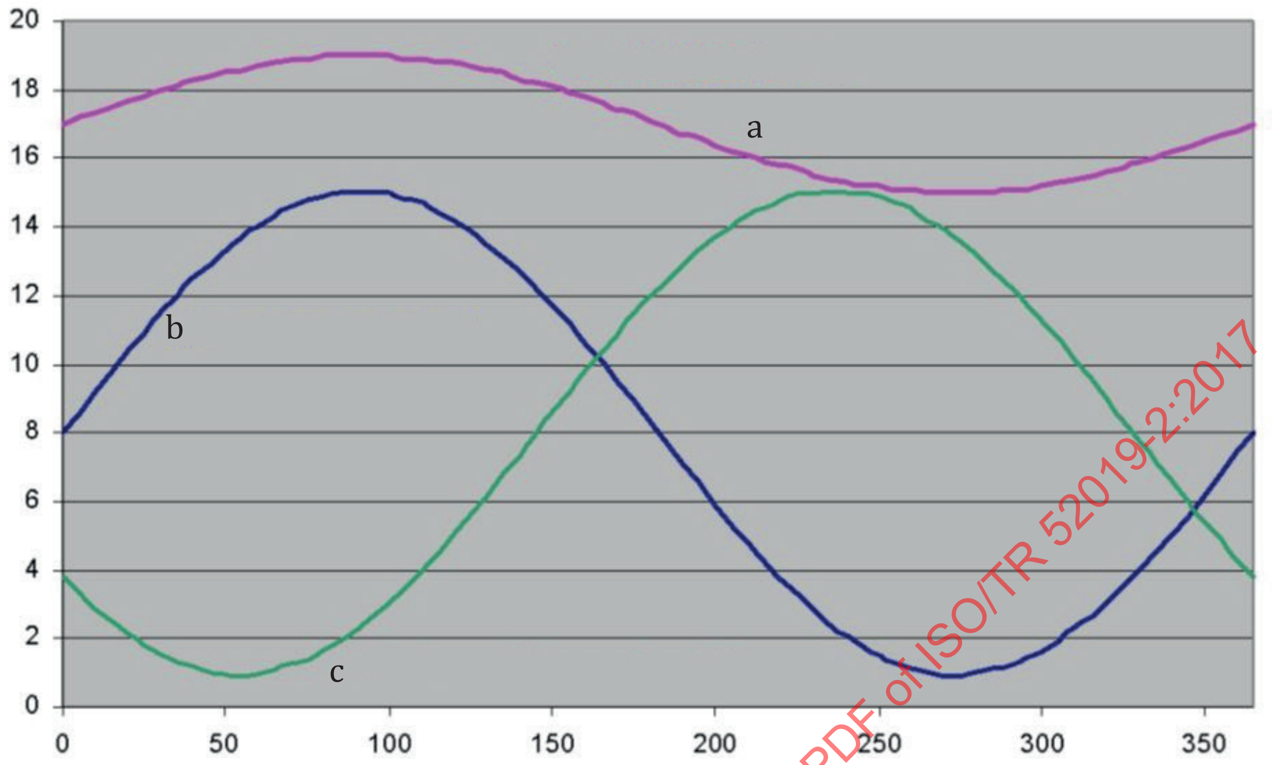
c outdoor temperature (°C)

d virtual ground temperature (°C)

Figure C.5 — Calculated internal temperature over six days

C.2.5 Validation simulation for larger floor

This case is the same as that in C.2.2 except that the length of each side is 10 m (100 m^2 floor area). The U-value of the floor is 0,107 W/(m^{2}K), so that the thermal conductivity assigned to the layer is 0,013 W/(m·K). The temperatures are shown in Figure C.5 and the calculated heat flows by the two methods are shown in Figure C.6.



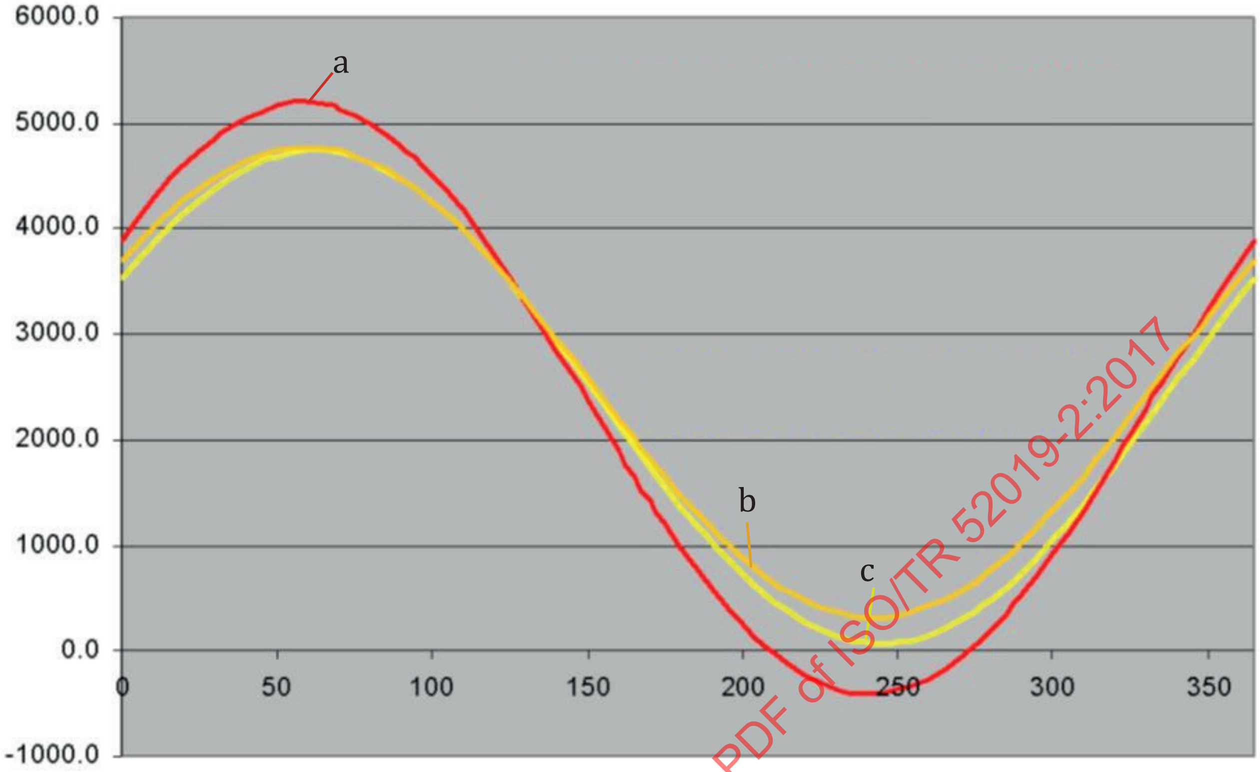
Key

a indoor temperature (°C)

b outdoor temperature (°C)

c virtual ground temperature (°C)

Figure C.6 — Results for sinusoidal temperature variations



Key

a heat loss (W) proposed method using 1D building simulation

b heat loss (W) 2D numerical method

c heat loss (W) 3D numerical method

Figure C.7 — Results for sinusoidal temperature variations

C.2.6 Conclusions

The method of using a virtual layer below the floor as described in ISO 13770:1997, Annex F provides a good approximation to results from 3D simulations in which the ground was included in the geometrical model.

Annex D
(informative)

ISO 13370: Slab-on-ground floor with an embedded heating or cooling system

For the purposes of this annex, the symbols and subscripts given in ISO 13370 apply.

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 ISO 13370, with the following modifications:

— replace the internal temperature, θ_{int}, by the average temperature in the plane of the heating elements, θ_h;

— include in the calculation of $d_{f;sog}$ 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, using Formula (D.1).

$$\theta_h = \theta_{int} + R_{int} \cdot \frac{(\Phi_h - \Phi_1)}{A} \tag{D.1}$$

where

θ_{int} is the average room temperature, in °C;

R_{int} is the thermal resistance between the internal environment and the plane of the heating element, in m²·K/W;

A is the area of floor, in m².

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 Formula (D.2).

$$\theta_h = \theta_i + \frac{R_{int} \cdot \Phi_2}{A} \tag{D.2}$$

Annex E
(informative)

ISO 13370: Cold stores

For the purposes of this annex, the symbols and subscripts given in ISO 13370 apply.

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 Annex E can also be used for other analogous situations, such as ice rinks.

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.

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.

The heat flow rate via the ground may be calculated in accordance with the procedures in ISO 13370, with the following modifications:

a) replace the internal temperature θ_{int} by the design temperature of the ground surface (e.g., 5 °C);

b) include in the thickness of slab on ground floor, $d_{f;sog}$, only any thermal resistance below the heating element, the wall thickness and external surface resistance.

The heat flow rate from the heating elements to the refrigerated space is given by Formula (E.1).

$$\Phi = A \cdot \left(\theta_g - \theta_{int}\right) \Big/ \left(R_{si} + R_{int}\right) \quad \text{(E.1)}$$

where

Φ is the heat flow rate, in W;

θ_{int} is the design internal temperature of the cold store, in °C;

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

R_{int} is the thermal resistance of all floor layers between the plane of the heating elements and the internal floor surface, in $m^2 \cdot K/W$.

Annex F
(informative)

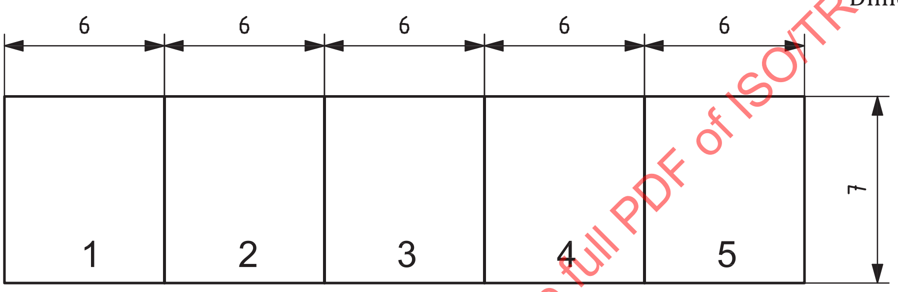
ISO 13370: Worked examples

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

F.1.1 Definition

Figure F.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 F.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).

F.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

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

$d_{f;sog} < B$, so

$$U_g = \frac{2 \times 1,5}{3,142 \times 5,676 + 0,615} \times \ln\left(\frac{3,142 \times 5,676}{0,615} + 1\right) = 0,1\ 626 \times \ln(30,00) = 0,553 \quad \text{W/(m}^2\text{·K)};$$

$$H_g = 0,553 \times 210 = 116,1 \quad W/K$$

F.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.

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

$d_{f;sog} = 0{,}615$ m, as before.

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

F.1.4 Houses 2, 3 and 4

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

$d_{f;sog} = 0{,}615$ m, as before.

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

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

Adding H_g for each house gives

$2 \times 27{,}4 + 3 \times 20{,}1 = 115{,}1$ 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.

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

F.2.1 Definition

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

$P = 10 + 6 + 6 + 3 + 4 + 9 = 38$ m.

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

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

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

Dimensions in metres

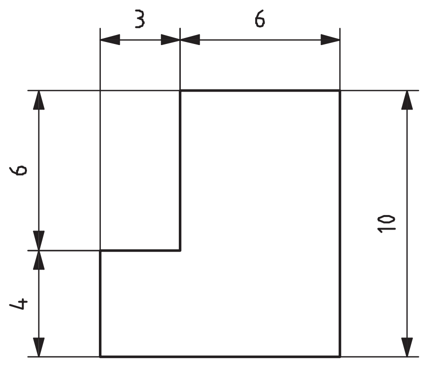


Figure F.2 — L-shaped building

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

$d_{f;sog}$ = 0,3 + 2,0 × (0,17 + 0 + 0,04) = 0,72 m

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

F.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 [see ISO 13370:1997, Formula (D.1)].

For the foundations: $R' = R_n - \frac{d_n}{\lambda}$

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.

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

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

D = 0,6 m;

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

U_g = 0,91 – 2 × 0,400/3,789 = 0,70 W/(m²·K)

F.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 m² K/W

$d_{f;sog}$ = 0,3 + 2,0 (0,17 + 0,625 + 0,04) = 1,97 m

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

F.2.5 Insulation of high thermal resistance

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

$R_f = 0{,}1/0{,}04 = 2{,}5$ m²·K/W

$d_{f;sog} = 0{,}3 + 2{,}0(0{,}17 + 2{,}5 + 0{,}04) = 5{,}72$ m;

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

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

In addition to all-over insulation as in F.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 F.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 m²·K/W. Additional insulation is provided at corners for frost protection, but this is ignored for the calculation of heat losses.

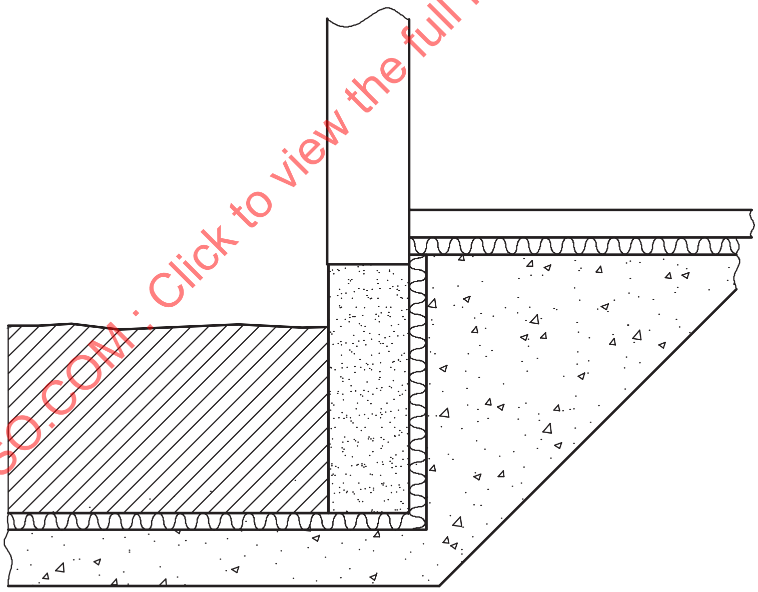


Figure F.3 — Edge insulation for frost protection

Following ISO 13370, 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:

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

so that the additional equivalent thickness is:

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

For the vertical insulation:

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

For the ground insulation:

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

Ψ_g for the vertical insulation provides the larger effect so that:

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

F.2.7 Thermal bridge at floor edge

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

As in F.2.5,

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

The numerical calculation in accordance with ISO 10211 gave:

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

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

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

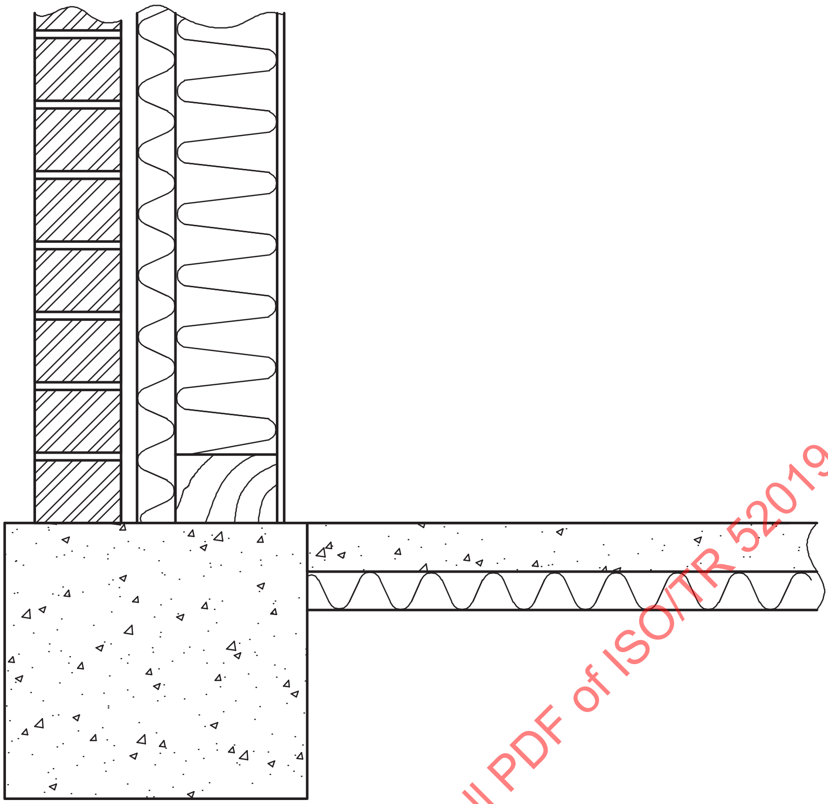


Figure F.4 — Thermal bridge at floor edge

F.3 Example 3: Suspended floor

F.3.1 Definition

Figure F.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.

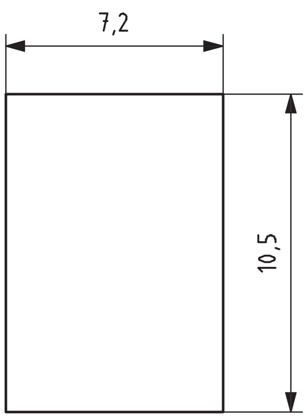


Figure F.5 — Dimensions of suspended floor

F.3.2 Without insulation

The suspended floor is uninsulated [U_f = 2,0 W/(m²·K)] and the walls of the underfloor space are uninsulated [U_w = 1,7 W/(m²·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 m;

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

$$U_x = \frac{2 \times 0,3 \times 1,7}{4,271} + \frac{1\,450 \times 0,002 \times 4,0 \times 0,05}{4,271} = 0,375 \text{ W/(m}^2\text{·K)}$$

Thus

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

F.3.3 Insulation of walls of underfloor space

Walls of underfloor space insulated such that

U_w = 0,5 W/(m²·K);

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

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

F.3.4 Insulation of suspended floor

Suspended floor insulated such that

U_f = 0,5 W/(m²·K);

U_x = 0,375 W/(m²·K), as in K.3.2;

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

F.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 m²; B = 4,286 m; z = 2,5 m;

R_f = 0 and R_w = 0,05/0,035 + 0,3/1,7 = 1,605 m² K/W;

$d_{f;sog}$ = 0,3 + 2,0 (0,17 + 0 + 0,04) = 0,72 m;

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

$d_{g;sog}$ + 0,5 z = 0,66 + 1,25 = 1,91

This is less than B, so

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

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

$H_g = A \cdot U_{bf} + z \cdot P \cdot U_{bw}$ = 75 × 0,533 + 2,5 × 35 × 0,302 = 66,4 W/K;

U = 66,4/(75 + 2,5 × 35) = 0,41 W/(m²·K)

F.5 Example 5: Monthly heat flow rate

Consider house 1 in Example 1, with insulation of thermal resistance 1,25 m²·K/W all over the floor. The mean monthly external temperatures are as specified in Table F.1.

Table F.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: $\bar{\theta}_i$ approximately (15 + 19)/2 = 17,0 °C;

— External: (sum of the above monthly values divided by 12): $\bar{\theta}_e$ = 7,98 °C.

Temperature amplitudes:

— Internal: $\bar{\theta}_i$ approximately (19 – 15)/2 = 2,0 K;

— External: $\bar{\theta}_e$ = (15,4 - 1,3)/2 = 7,05 K.

P = 19 m; A = 42 m²; B' = 4,421 m; λ = 1,5 W/(m·K); $d_{f;sog}$ = 2,49 m;

U = 0,345 W/(m²·K); H_g = 14,49 W/K

Using δ = 2,2 m:

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

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

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

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

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

Table F.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 F.2 is 133 W.

Alternatively, ignoring the phase difference, the average heat flow rate over the heating season is (see Table F.3):

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

$$= 135 \text{ W}$$

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

Annex G
(informative)

ISO 13786: Principle of the method and examples of applications

G.1 Principle

For the purposes of this annex, the symbols and subscripts given in ISO 13786 apply.

The method given in ISO 13786 is based on heat conduction in building components composed of several plane, parallel, homogeneous layers, under regular sinusoidal boundary conditions and one dimensional heat flow.

That means that at any location in the component, the temperature variations can be modelled by Formula (G.1).

$$\theta_n(x,t) = \bar{\theta}(x) + \frac{\hat{\theta}_{+n}(x) \cdot e^{j \cdot \omega \cdot t} + \hat{\theta}_{-n}(x) \cdot e^{-j \cdot \omega \cdot t}}{2} \tag{G.1}$$

and the variations of the density of heat flow rate by Formula (G.2).

$$q_n(x,t) = \bar{q}(x) + \frac{\hat{q}_{+n}(x) \cdot e^{j \cdot \omega \cdot t} + \hat{q}_{-n}(x) \cdot e^{-j \cdot \omega \cdot t}}{2} \tag{G.2}$$

With Formula (G.3).

$$\hat{\theta}_{\pm}(x) = \left|\hat{\theta}(x)\right| \cdot e^{\pm j \cdot \psi} \text{ and } \hat{q}_{\pm}(x) = \left|\hat{q}(x)\right| \cdot e^{\pm j \cdot \varphi} \tag{G.3}$$

Temperature and density of heat flow rate variations are those around the mean values $\bar{\theta}$ and $\bar{q}$ of these variables, which are linked by Formula (G.4).

$$\bar{q} = U \cdot \left(\bar{\theta}_i - \bar{\theta}_e\right) \tag{G.4}$$

where U is the thermal transmittance of the component.

The one dimensional equation of heat can be solved for a single layer of homogenous material with sinusoidal boundary conditions, the element being represented by the heat transfer matrix.

The heat transfer matrix, $\boldsymbol{Z}$, then allows the calculation of the variations of the temperature, θ_2, and of the density of heat flow rate, q_2, on one side of the building component, when these quantities, θ_1 and q_1, are known on the other side.

The elements of the heat transfer matrix have the physical interpretation indicated below. Each element is a complex number, which can be represented by its modulus, $|\boldsymbol{Z}_{mn}|$, and its argument, $\varphi_{mn} = \arg(\boldsymbol{Z}_{mn})$.

— $|\boldsymbol{Z}_{11}|$ is a temperature amplitude factor, i.e. the amplitude of the temperature variations on side 2 resulting from an amplitude of 1 K on side 1.

— φ_{11} is the phase difference between temperatures on both sides of the component.

— $|\boldsymbol{Z}_{21}|$ gives the amplitude of the density of heat flow rate through side 2 resulting from a periodic variation of temperature on side 1 with an amplitude of 1 K.

— φ_{21} is the phase difference between the density of heat flow rate through side 2 and the temperature of side 1.

— $|\boldsymbol{Z}_{12}|$ gives the amplitude of the temperature on side 2 when side 1 is subjected to a periodically varying density of heat flow rate with an amplitude of 1 W/m^2.

— φ_{12} is the phase difference between the temperature on side 2 and the density of heat flow rate through side 1.

— $|\boldsymbol{Z}_{22}|$ is the heat flow rate amplitude factor, i.e. the amplitude of the variations of the density of heat flow rate through side 2 resulting from an amplitude of density of heat flow rate of 1 W/m^2 through side 1.

— φ_{22} is the phase difference between the densities of heat flow rate through both sides of the component.

The time delays between the maximum of an effect and the maximum corresponding cause can be calculated from the phase shift of the transfer matrix element, $\boldsymbol{Z}_{ij}$ in Formula (G.5).

$$\Delta t_{ij} = \frac{T}{2\pi} \cdot \varphi_{ij} = \frac{T}{2\pi} \cdot \arg\left(\boldsymbol{Z}_{ij}\right) \tag{G.5}$$

G.2 Examples of application

G.2.1 General

The applications of the dynamic thermal characteristics are numerous. Some general examples are given in G.2.2 and G.2.3.

G.2.2 One component

The heat transfer matrix, $\boldsymbol{Z}$, can be used for any application linking the boundary conditions on one side to the temperature and heat flow on the other side.

For example, the heat flow rate required to maintain a constant temperature on side 2 despite temperature and heat flow rate variations on side 1 is given by Formula (G.6).

$$\hat{q}_2 = \boldsymbol{Z}_{21} \cdot \hat{\theta}_1 + \boldsymbol{Z}_{22} \cdot \hat{q}_1 \tag{G.6}$$

Similarly, the variation of the temperature on side 2 can be obtained by Formula (G.7).

$$\hat{\theta}_2 = \boldsymbol{Z}_{11} \cdot \hat{\theta}_1 + \boldsymbol{Z}_{12} \cdot \hat{q}_1 \tag{G.7}$$

The variations of heat flow rate entering into the component on both sides can be calculated from the variations of temperatures by solving Formula (G.8) for the densities of heat flow rates:

$$\begin{pmatrix} \hat{q}_1 \\ -\hat{q}_2 \end{pmatrix} = \frac{1}{\boldsymbol{Z}_{12}} \cdot \begin{pmatrix} -\boldsymbol{Z}_{11} & 1 \\ 1 & -\boldsymbol{Z}_{22} \end{pmatrix} \cdot \begin{pmatrix} \hat{\theta}_1 \\ \hat{\theta}_2 \end{pmatrix} \tag{G.8}$$

NOTE The sign of $\hat{q}_2$ is changed because the positive direction is going out of the element at side 2.

Thermal admittance is the amplitude of the density of heat flow rate on one side resulting from a unit temperature amplitude on the same side, when the temperature amplitude on the other side is zero [Formulae (G.9) and (G.10)].

$$Y_{11} = \frac{\hat{q}_1}{\hat{\theta}_1} \text{ for } \hat{\theta}_2 = 0\text{, so } Y_{11} = -\frac{\boldsymbol{Z}_{11}}{\boldsymbol{Z}_{12}} \quad \text{(G.9)}$$

$$Y_{22} = \frac{-\hat{q}_2}{\hat{\theta}_2} \text{ for } \hat{\theta}_1 = 0\text{, so } Y_{22} = -\frac{\boldsymbol{Z}_{22}}{\boldsymbol{Z}_{12}} \quad \text{(G.10)}$$

Periodic thermal transmittance is amplitude of the density of heat flow rate on one side when the temperature amplitude on that side is zero and there is unit temperature amplitude on the other side [Formula (G.11)].

$$Y_{12} = \frac{\hat{q}_2}{\hat{\theta}_1} \text{ for } \hat{\theta}_2 = 0\text{, so } Y_{12} = -\frac{1}{\boldsymbol{Z}_{12}} \quad \text{(G.11)}$$

NOTE Y_{22} is, in general, different from Y11, but always $Y_{21} = Y_{12}$.

Heat capacities represent the ability of a building component to store energy from either side when the corresponding temperature varies periodically.

The component having heat capacity C_1 on one side will store, on that side, an amount of energy equal to [Formula (G.12)]:

$$Q = 2 \cdot C_1 \cdot \left|\hat{\theta}_1\right| \quad \text{(G.12)}$$

resulting from a periodic change in the temperature of side 1 from $-\left|\hat{\theta}_1\right|$ to $+\left|\hat{\theta}_1\right|$ during a half period. The same applies to side 2.

G.2.3 Several components

When several components are linked to the same zone, j [Formula (G.13)],

$$\hat{\Phi}_j = \sum_k \left(L_{11,k} \cdot \hat{\theta}_j - L_{12,k} \cdot \hat{\theta}_k \right) \quad \text{(G.13)}$$

where the summation is over all zones, k, that are thermally connected to zone j. The thermal conductances can be calculated directly by solving the time-dependent equation of heat transfer using a geometrical model in accordance with ISO 10211. For components in which one dimensional heat flow can be assumed, however, the calculation method provided in this International Standard can be used to obtain $L_{mn,k}$.

For example, let us consider a cold store built outside and consisting of two types of components: the walls and the roof. Assuming that these components have a relatively small thermal inertia, only the daily variations are considered. It is also assumed that the mass of the products stored in the cold store should not be taken into account and that the cold store is well insulated from the ground. Therefore, as far as thermal bridges can be neglected, the daily average cooling power, $\overline{\Phi}_i$, required to maintain a fixed internal temperature, θ_i, when the daily average external temperature is $\overline{\theta}_e$, is [Formula (G.14)]:

$$\overline{\Phi}_i = \left(A_w \cdot U_w + A_r \cdot U_r\right) \cdot \left(\overline{\theta}_e - \theta_i\right) \quad \text{(G.14)}$$

where

A_r is the area of the roof;

U_r is steady-state thermal transmittance of the roof;

A_w is the area of the wall;

U_w is the steady-state thermal transmittance of the wall.

A negative cooling power means a heating power.

However, some supplementary power can be required to maintain a constant internal temperature despite a daily variation of the external temperature. If this variation is considered as sinusoidal of amplitude $\hat{\theta}_e$, this supplementary power amplitude will be [Formula (G.15)]:

$$\hat{\Phi}_i = \left| A_w \cdot Y_{12,w} + A_r \cdot Y_{12,r} \right| \cdot \hat{\theta}_e \qquad (G.15)$$

where Y_{12} is calculated with a period of 24 h and with the innermost layer as the first layer. Here again, thermal bridges are neglected. The total peak power will then be [Formula (G.16)]:

$$\Phi_p = \bar{\Phi}_i + \hat{\Phi}_i \qquad (G.16)$$

NOTE 1 The simplifying assumptions in this example are made for sake of simplicity and are not necessary. For example, solving the heat transfer equation for two- and three-dimensional heat flow allows one to take account of heat transfer to the ground and thermal bridges. Higher thermal inertia and non-sinusoidal (but periodic) external temperature variations can be considered by using a representation of the temperature and heat flow as Fourier series, with several time periods (1, 2, 4, 8, ... days).

NOTE 2 The absorption of solar radiation on the external surface could be taken into account as an external heat flow, or by introducing an equivalent radiation temperature.

Annex H
(informative)

ISO 13786: Information for computer programming

H.1 General

For the purposes of this annex, the symbols and subscripts given in ISO 13786 apply.

The calculations of dynamic thermal characteristics will usually be done on a computer. The following can assist the programmer.

H.2 Flowchart for the calculation method

Figure H.1 shows the sequence of operations, from top to bottom.

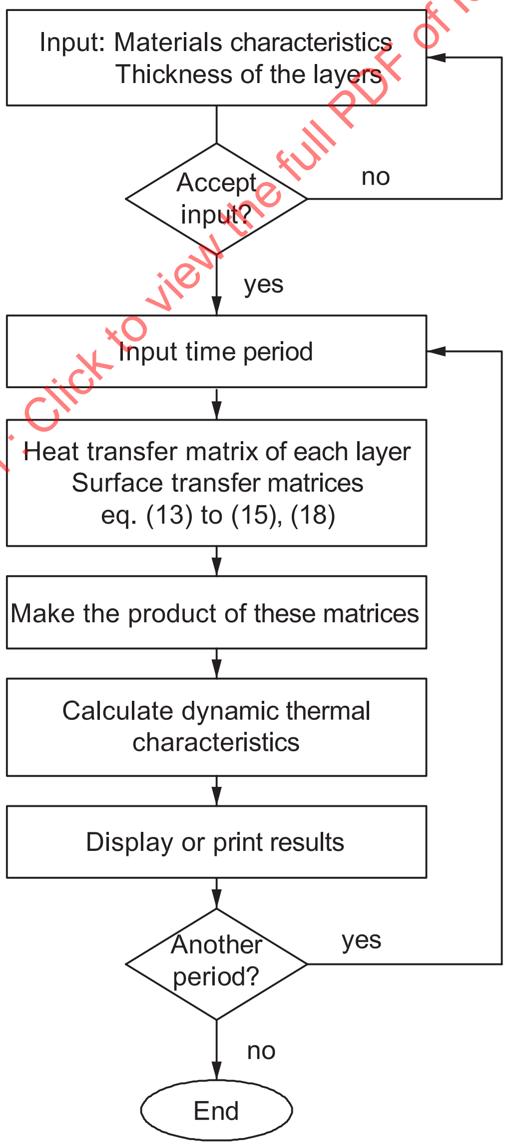


Figure H.1 — Flowchart of the calculation method

H.3 Representation of complex numbers

The calculation requires computation with complex numbers. This can be done on computers, even if the mathematical language does not include complex numbers, by using the technique presented below.

Let a and b be respectively the real and imaginary parts of a complex number, z. This number can be represented in matrix notation in Formula (H.1):

$$z = \begin{pmatrix} a & b \\ -b & a \end{pmatrix} \tag{H.1}$$

This changes a complex number into a real matrix of order 2, and a complex matrix of order 2 into a real matrix of order 4. Then the calculations with complex numbers are replaced by conventional matrix calculations. The matrix resulting from the calculation contains, in its odd rows, the real and imaginary parts of the corresponding complex number.

The modulus and argument of a complex number can be obtained from the real and imaginary parts by Formula (H.2)

$$\left| z \right| = \sqrt{a^2 + b^2} \tag{H.2}$$

Assuming that the arctan function is evaluated in the range −π/2 to +π/2, arg(z) is obtained from the appropriate formula in Table H.1.

Table H.1 — Argument of complex number

Values of a and b	arg(z) for admittance	arg(z) for periodic thermal transmittance
$b = 0$	0	0
$a > 0, b > 0$	$\arctan\left(\frac{b}{a}\right)$	$\arctan\left(\frac{b}{a}\right) - 2\pi$
$a = 0, b > 0$	$\pi/2$	$-3\pi/2$
$a < 0, b > 0$	$\arctan\left(\frac{b}{a}\right) + \pi$	$\arctan\left(\frac{b}{a}\right) - \pi$
$a > 0, b < 0$	$\arctan\left(\frac{b}{a}\right) + 2\pi$	$\arctan\left(\frac{b}{a}\right)$
$a = 0, b < 0$	$3\pi/2$	$-\pi/2$
$a < 0, b < 0$	$\arctan\left(\frac{b}{a}\right) + \pi$	$\arctan\left(\frac{b}{a}\right) - \pi$

Annex I
(informative)

ISO 13786: Examples

I.1 Example 1: Single layer component

A 200 mm wall is made up of homogeneous concrete. Its physical characteristics are:

— thermal conductivity, λ = 1,8 W/(m·K);

— density, ρ = 2 400 kg/m^3;

— specific heat capacity, c = 1 000 J/(kg·K).

Then, for a period of 24 h:

— periodic penetration depth δ = 0,144 m and ξ = 1,393.

The elements of the heat transfer matrix of the concrete layer are then:

Z_{11} = 0,378 8 + 1,858j

Z_{12} = −0,097 25 – 0,075 4j

Z_{21} = 22,16 – 30,55j

Z_{22} = 0,378 8 + 1,858j

Taking account of surface resistances of 0,13 m^2·K/W inside and 0,04 m^2·K/W outside, the transfer matrix of the wall is:

Z_{11} = −0,508 + 3,081j

Z_{12} = −0,046 – 0,545j

Z_{21} = 22,16 – 30,55j

Z_{22} = −2,502 + 5,830j

Solving the transfer matrix in accordance with ISO 13786 gives the results in Table I.1.

Table I.1 — Dynamic thermal characteristics for Example 1

Property	Modulus	Time shift h
Internal thermal admittance, Y_{11}	5,70 W/(m^2·K)	0,95
External thermal admittance, Y_{22}	11,59 W/(m^2·K)	1,87
Periodic thermal transmittance, Y_{12}	1,83 W/(m^2·K)	−5,68
Internal areal heat capacity, κ_1	86 kJ/(m^2·K)	—
External areal heat capacity, κ_2	171 kJ/(m^2·K)	—
Thermal transmittance, U	3,56 W/(m^2·K)	—
Decrement factor, f	0,514	—

Areal heat capacities (without surface resistances) are:

— exact values:

  — inside: κ_1 = 224 kJ/(m^2·K);

  - outside: κ_2 = 224 kJ/(m²·K);
- effective thickness approximation (see ISO 13786):
  - inside: κ_1 = 240 kJ/(m²·K);
  - outside: κ_2 = 240 kJ/(m²·K).

Areal heat capacities (with surface resistances) are:

- exact values:
  - inside: κ_1 = 86 kJ/(m²·K);
  - outside: κ_2 = 171 kJ/(m²·K);
- effective thickness approximation (see ISO 13786):
  - inside: κ_1 = 97 kJ/(m²·K);
  - outside: κ_2 = 197 kJ/(m²·K).

I.2 Example 2: Multilayer component

A concrete wall is insulated outside with 100 mm polystyrene foam coated with a convenient finishing. Material properties are given in Table I.2. The results of calculation are in Tables I.3 to I.5.

Table I.2 — Thermal properties of materials for Example 2

Material	λ	ρ	c	d	R	a	δ	ξ
	W/(m·K)	kg/m³	J/(kg·K)	m	m²·K/W	mm²/s	m	—
Internal surface	—	—	—	—	0,130	—	—	—
Concrete	1,80	2 400	1 000	0,200	0,111	0,75	0,144	1,393
Thermal insulation	0,04	30	1 400	0,100	2,500	0,95	0,162	0,618
Coating	1,00	1 200	1 500	0,005	0,005	0,56	0,124	0,040
External surface	—	—	—	—	0,040	—	—	—

Table I.3 — Elements of the heat transfer matrices in both directions

Matrix	Element of matrix	Modulus	Time shift (in range −12 h to 12 h) h
Heat transfer matrix	Z_{11}	98,12	8,96
	Z_{21}	83,07 W/(m²·K)	0,99
	Z_{12}	16,51 m²·K/W	−3,89
	Z_{22}	13,99	−11,86
Inverse matrix	Z'_{11}	13,99	−11,86
	Z'_{21}	83,07 W/(m²·K)	−11,01
	Z'_{12}	16,51 m²·K/W	8,11
	Z'_{22}	98,12	8,96

Large differences appear when the component is seen from the high-mass side or from the insulated side.

Table I.4 — Dynamic thermal characteristics for Example 2

Property	Modulus	Time shift h
Internal thermal admittance, Y_{11}	5,94 W/(m^2·K)	0,85
External thermal admittance, Y_{22}	0,85 W/(m^2·K)	4,03
Periodic thermal transmittance, Y_{12}	0,061 W/(m^2·K)	−8,11
Internal areal heat capacity, κ_1	82 kJ/(m^2·K)	—
External areal heat capacity, κ_2	12 kJ/(m^2·K)	—
Thermal transmittance, U	0,359 W/(m^2·K)	—
Decrement factor, f	0,169	—

The capacity under harmonic conditions (24 h period) is less than the long term (steady-state) capacity, which is the sum of $d \cdot \rho \cdot c$ for each layer, or 493 kJ/(m^2·K).

Table I.5 — Areal heat capacities in accordance with the simplified calculation in ISO 13788

Approximations	Areal heat capacity, kJ/(m^2·K)	
	without R_s	**with R_s**
Internal, semi-infinite	244	97
Internal, effective thickness	240	97
External, thin layer	9	9

When surface resistance is taken into account, there is little difference between the values calculated by the detailed and the values obtained from the simplified method.

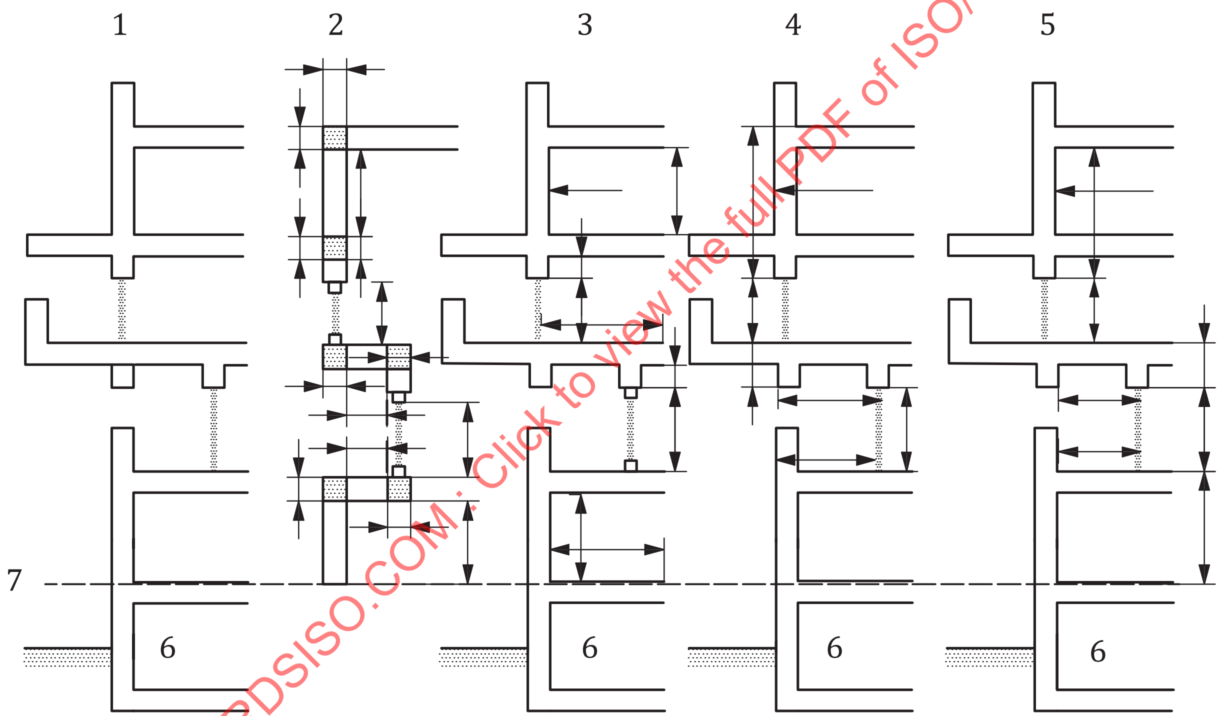
Annex J
(informative)

ISO 13789: Information on type of dimensions

For the purposes of this annex, the symbols and subscripts given in ISO 13789 apply.

To calculate the transmission heat transfer coefficient, the building envelope is divided into elements (see Figure J.1). However, building element dimensions are usually measured according to one of three systems: internal, overall internal, and external. These differ in the way that the plane areas of junctions between elements are included in the areas of these elements themselves.

Thus, for example, the term $\Sigma A_i \cdot U_i$ is larger when using external dimensions than when using internal dimensions. Consequently, the values of Ψ_k are generally smaller for external dimensions, and can even be negative in some cases such as external corners.



Key

1 reality
2 elements
3 internal dimensions
4 external dimensions
5 overall internal dimensions
6 unheated
7 ISO 13370 applies to heat transfers below this boundary

NOTE 1 For a heated basement dimensions are measured to the basement floor slab.

NOTE 2 External dimensions can also be measured to the bottom of the floor slab.

Figure J.1 — Examples of methods for determining building element dimensions

When the principal insulation layer is continuous, the linear thermal transmittance of some junctions can be small, particularly when external or overall internal dimensions are used. They are often neglected in those cases. As a consequence, slight differences in the calculated values of the transmission heat transfer coefficient can arise between dimension systems, if certain thermal bridges are neglected under one system but not under another one.

Therefore, it is recommended, in particular in case of dispute, that the building is assessed using the dimensions of each individual element (second left in Figure J.1). In this method, the linear thermal transmittance of each junction is explicitly included.

Annex K
(informative)

ISO 13789: Ventilation airflow rates

K.1 General

For the purposes of this annex, the symbols and subscripts given in ISO 13789 apply.

Annex K provides a method to calculate the airflow rate in buildings which can be applied in the absence of a method in international standards or in national provisions.

K.2 Air tightness level

The tightness level is defined from ranges of air change rate at 50 Pa pressure difference between indoor and outdoor, n_{50}, according to Table K.1. n_{50} includes air flow rates through closed air inlets.

Table K.1 — Air tightness levels as used in this annex

Air change rate at 50 Pa h^{-1}		Envelope tightness level
Multi-family buildings	**Single family buildings**	
Less than 2	Less than 4	High
2 to 5	4 to 10	Medium
More than 5	More than 10	Low

NOTE 1 The difference between multi-family and single-family buildings is related to the typical difference in their external wall areas for a given internal volume.

NOTE 2 In residential buildings with n50 less than 3 h-1 (with open air inlets), minimum ventilation requires opening windows at appropriate intervals.

K.3 Minimum ventilation rate

For comfort and hygienic reasons a minimum ventilation rate is needed when the building is occupied. This minimum ventilation rate can be determined on a national basis, taking account of the building type and the pattern of occupancy for the building.

Typical values are:

$\dot{V}_{min}$ = 0,3 × V [m^3/h], where V is the ventilated volume in m^3, for residential buildings;

$\dot{V}_{min}$ = 30 m^3/h per person (during occupancy) for non-residential buildings

K.4 Natural ventilation

K.4.1 Total ventilation rate

The total ventilation rate is determined as the greater of the minimum ventilation rate, $\dot{V}_{min}$, and the design ventilation rate, $\dot{V}_d$ [Formula (K.1)]:

$$\dot{V} = \max\left[\dot{V}_{min};\dot{V}_d\right] \quad (K.1)$$

where

$\dot{V}_{min}$ is the minimum ventilation rate;

$\dot{V}_d$ is the design ventilation rate.

$\dot{V}_d$ should be specified on a national basis. Where no national information is available, the air change rate in residential buildings may be assessed from Table K.2 or Table K.3.

K.4.2 Data for estimation of natural ventilation

The ventilation rate by natural ventilation can be determined on a national basis, taking into account the climate, the surroundings, the building type and geometry, and the size and the position of the openings. Where no national information is available the monthly average ventilation rate during the heating season may be taken from Table K.2 or Table K.3.

Table K.2 — Air change rate, *n*, in h^{-1}, in naturally ventilated multi-family buildings, determined from shielding class and building tightness

Shielding class[a]	More than one exposed facade			Only one exposed facade		
	Tightness of building			Tightness of building		
	Low	Medium	High	Low	Medium	High
No shielding	1,2	0,7	0,5	1,0	0,6	0,5
Moderate	0,9	0,6	0,5	0,7	0,5	0,5
Heavy shielding	0,6	0,5	0,5	0,5	0,5	0,5

[a] Shielding classes are defined in Table K.4

Table K.3 — Air change rate, *n*, in h^{-1} in naturally ventilated single family houses, determined from shielding class and building tightness

Shielding class	Tightness of building		
	Low	Medium	High
No shielding	1,5	0,8	0,5
Moderate	1,1	0,6	0,5
Heavy shielding	0,7	0,5	0,5

K.5 Mechanical ventilation systems

The total airflow rate is determined as the sum of the ventilation rate determined from the average airflow rates through the system fans when in operation, $\dot{V}_f$, and an additional airflow rate, $\dot{V}_x$, induced by wind effects through ventilation openings and infiltration cracks [Formula (K.2)]:

$$\dot{V} = \dot{V}_f + \dot{V}_x \tag{K.2}$$

where

$\dot{V}_f$ is the average airflow rate through the system fans when in operation;

$\dot{V}_x$ is the additional airflow rate with fans on, due to wind effects.

For supply only systems, $\dot{V}_f$ is equal to the supply airflow rate, $\dot{V}_1$, and for exhaust only systems it is equal to the exhaust flow rate, $\dot{V}_2$.

For balanced ventilation systems, $\dot{V}_f$ is equal to the greater of the supply airflow rate, $\dot{V}_1$, and the exhaust airflow rate, $\dot{V}_2$.

The additional airflow rate, $\dot{V}_x$, can be calculated from Formula (K.3):

$$\dot{V}_x = \frac{V \cdot n_{50} \cdot e}{1 + \frac{f}{e} \cdot \left[\frac{\dot{V}_1 - \dot{V}_2}{V \cdot n_{50}} \right]^2} \tag{K.3}$$

where

V is the ventilated volume;

n_{50} is the air change rate resulting from a pressure difference of 50 Pa between inside and outside, including the effects of air inlets;

$\dot{V}_1$ is the supply airflow rate;

$\dot{V}_2$ is the exhaust airflow rate;

e, f are shielding coefficients which can be found in Table K.4.

NOTE Formula (K.3) is an empirical one derived from numerical simulations over complete years. It is based on additional flow when there are large wind-induced pressure difference, assuming no additional flow for lower wind speeds.

Table K.4 — Shielding coefficients, *e* and *f*, for calculation of additional air flow rate using Formula (K.3)

Shielding class	Description	Coefficient *e*	
		More than one exposed facade	One exposed facade
No shielding	Buildings in open country, high rise buildings in city centres	0,10	0,03
Moderate	Buildings in the country with trees or other buildings around them, suburbs	0,07	0,02
Heavy shielding	Buildings of average height in city centres, buildings in forests	0,04	0,01
		Coefficient f	
All		15	20

If there is mechanical ventilation switched on for a part of the time, the airflow rate is calculated by Formula (K.4):

$$\dot{V} = \left(\dot{V}_0 + \dot{V}_x'\right) \cdot \left(1 - \beta\right) + \left(\dot{V}_f + \dot{V}_x\right) \cdot \beta \qquad \text{(K.4)}$$

where

$\dot{V}_f$ is the average airflow rate through the system fans when in operation;

$\dot{V}_x$ is the additional airflow rate with fans on, due to wind effects;

$\dot{V}_0$ is the airflow rate with natural ventilation, including airflow through ducts of mechanical system;

$\dot{V}_x'$ is the additional airflow rate with fans off, due to wind effects: $\dot{V}_x' = V \cdot n_{50} \cdot e$;

β is the fraction of the time period with fans on.

In non-residential buildings, mechanical ventilation systems may be off for a large part of the time. This is taken into account through the definition of different periods or through the evaluation of β. A poor evaluation of β or a poor definition of periods may lead to large errors in the results.

For mechanical systems with variable design airflow rate, $\dot{V}_f$ is the average airflow rate through the fans during their running time.

K.6 Mechanical systems with heat exchangers

For buildings with heat exchange between exhaust air and supply air, the heat transfer by the mechanical ventilation is reduced by the factor (1 - η_V) where η_V is the global efficiency of the heat recovery system. This efficiency is always smaller than the effectiveness of the heat exchanger itself. It should take account of differences between supply and extract airflow rates, heat losses from ductwork outside the conditioned space, leakage and infiltration through the building envelope, recirculation of air, and de-frosting of the heat exchanger.

The effective air flow rate for heat transfer calculation when fans are on is determined from Formula (K.5):

$$\dot{V} = \dot{V}_f \cdot \left(1 - \eta_v\right) + \dot{V}_x \qquad \text{(K.5)}$$

where

$\dot{V}_f$ is the design airflow rate due to mechanical ventilation;

$\dot{V}_x$ is the additional airflow rate with fans on, due to wind effects;

η_v is the global heat recovery efficiency, taking account of the differences between supply and extract airflow rates. Heat in air leaving the building through leakage cannot be recovered.

For systems with heat recovery from the exhaust air to the hot water or space heating system via a heat pump, the ventilation rate is calculated without any reduction. Instead, the reduction in energy use due to heat recovery is allowed for in the calculation of the energy use of the relevant system.

Annex L
(informative)

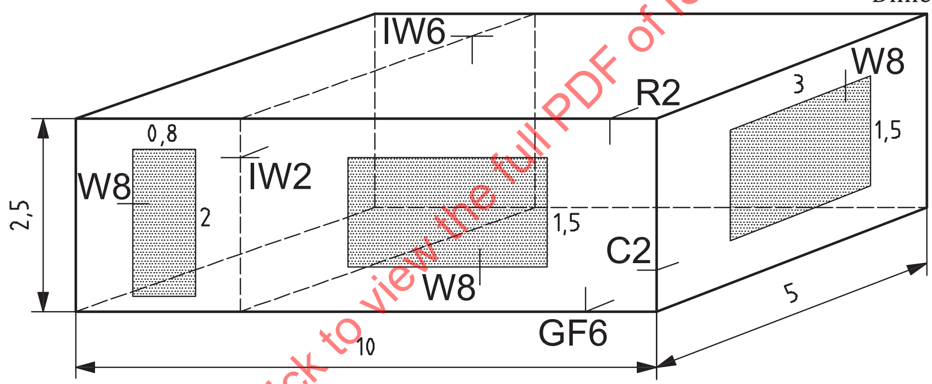
ISO 14683: Example of the use of default values of linear thermal transmittance in calculating the heat transfer coefficient

L.1 Example building

For the purposes of this annex, the symbols and subscripts given in ISO 14683 apply.

Figure L.1 shows the schematic diagram of a single-storey building with a flat roof, solid ground floor, one partition wall, and two windows and a door in the external wall. The overall internal dimensions of the plane building elements are given in metres, and the location of the thermal bridge types are marked. IW2, R2, etc. refer to the types of thermal bridge, as illustrated in Table L.2.

Dimensions in metres



Key

C2, GF6, IW2, IW6, R2, W8 types of thermal bridge

Figure L.1 — Sketch of a building showing the overall internal dimensions and the location of the thermal bridges

The transmission heat transfer coefficient, H_D, (ignoring point thermal bridges) is given by Formula (L.1):

$$H_D = \sum_i A_i \cdot U_i + \sum_k l_k \cdot \Psi_k \quad \text{(L.1)}$$

L.2 Using overall internal dimensions

The heat transfer coefficient through the various plane building elements is calculated in Table L.1. The value of U for each building element is multiplied by the overall internal area, A_{oi}, over which it applies, and the sum of these products gives the heat transfer coefficient through these building elements.

The value of the heat transfer coefficient through the two-dimensional thermal bridges is given in Table L.2. The value of Ψ_{oi} for each thermal bridge is multiplied by the length, l, over which it applies, and the sum of these products gives the heat transfer coefficient through these thermal bridges.

Table L.1 — Heat transfer coefficient through the plane building elements using overall internal dimensions

Building element	U W/(m²·K)	A_{oi} m²	$U \cdot A_{oi}$ W/K
Walls	0,40	64,4	25,76
Roof	0,30	50,0	15,00
Ground floor[a]	0,35	50,0	17,50
Windows	3,50	9,0	31,50
Door	3,00	1,6	4,80
		Total	94,56

[a] The thermal transmittance of the floor is calculated in accordance with ISO 13370.

Table L.2 — Heat transfer coefficient through the two-dimensional thermal bridges using overall internal dimensions

Thermal bridge	Thermal bridge type[a]	Ψ_{oi} W/(m·K)	l_{oi} m	$\Psi_{oi} \cdot l_{oi}$ W/K
Wall/roof	R2	0,75	30,0	22,50
Wall/wall	C2	0,10	10,0	1,00
Wall/ground floor	GF6	0,60	30,0	18,00
Partition/wall	IW2	0,95	5,0	4,75
Partition/roof	IW6	0,00	5,0	0,00
Lintel, sill, reveal	W8	1,00	23,6	23,60
			Total	69,85

[a] From Table C.2.

From Tables L.1 and L.2, Formula (L.2):

$$H_D = \sum_i A_i \cdot U_i + \sum_k l_k \cdot \Psi_k = 94,56 + 69,85 = 164,41 \quad \text{W/K} \tag{L.2}$$

Using overall internal dimensions, the heat transfer coefficient through the thermal bridges is 42 % of the total.

L.3 Using external dimensions

Assuming that the thickness of the wall is 0,3 m, that of the roof is 0,25 m and that of the floor is 0,25 m, and adding these thicknesses to the overall internal dimensions, gives external dimensions of the building of 10,6 m × 5,6 m × 3,0 m. The heat transfer coefficient through the various plane building elements using external dimensions is calculated in Table L.3. The value of U for each building element is multiplied by the external area, A_e, over which it applies, and the sum of these products gives the heat transfer coefficient through these building elements.

The calculated value of the heat transfer coefficient through the two-dimensional thermal bridges using external dimensions is given in Table L.4. The value of Ψ_e for each thermal bridge is multiplied by the length, l_e, over which it applies, and the sum of these products gives the heat transfer coefficient through these thermal bridges.

