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Building environment design — Embedded radiant heating and cooling systems —

Part 2: Determination of the design heating and cooling capacity

Conception de l'environnement des bâtiments — Systèmes intégrés de chauffage et de refroidissement par rayonnement —

Partie 2: Détermination de la puissance calorifique et frigorifique à la conception

Reference number
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Foreword

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

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).

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This document was prepared by Technical Committee ISO/TC 205, *Building environment design*, in collaboration with the European Committee for Standardization (CEN) Technical Committee CEN/TC 228, *Heating systems and water based cooling systems in buildings,* in accordance with the Agreement on technical cooperation between ISO and CEN (Vienna Agreement).

This second edition cancels and replaces the first edition (ISO 11855-2:2012), which has been technically revised.

The main changes compared to the previous edition are as follows:

— update of the figures for type A and C,

— update of the thermal, relevant material characteristics,

— editorial corrections.

A list of all parts in the ISO 11855 series can be found on the ISO website.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

The radiant heating and cooling system consists of heat emitting/absorbing, heat supply, distribution, and control systems. The ISO 11855 series deals with the embedded surface heating and cooling system that directly controls heat exchange within the space. It does not include the system equipment itself, such as heat source, distribution system and controller.

The ISO 11855 series addresses an embedded system that is integrated with the building structure. Therefore, the panel system with open air gap, which is not integrated with the building structure, is not covered by this series.

The ISO 11855 series is applicable to water-based embedded surface heating and cooling systems in buildings. The ISO 11855 series is applied to systems using not only water but also other fluids or electricity as a heating or cooling medium. The ISO 11855 series is not applicable for testing of systems. The methods do not apply to heated or chilled ceiling panels or beams.

The object of the ISO 11855 series is to provide criteria to effectively design embedded systems. To do this, it presents comfort criteria for the space served by embedded systems, heat output calculation, dimensioning, dynamic analysis, installation, control method of embedded systems, and input parameters for the energy calculations.

The ISO 11855 series consists of the following parts, under the general title Building environment design — Embedded radiant heating and cooling systems:

— *Part 1: Definitions, symbols, and comfort criteria*

— *Part 2: Determination of the design heating and cooling capacity*

— *Part 3: Design and dimensioning*

— *Part 4: Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)*

— *Part 5: Installation*

— *Part 6: Control*

— Part 7: *Input parameters for the energy calculation*

ISO 11855-1 specifies the comfort criteria which should be considered in designing embedded radiant heating and cooling systems, since the main objective of the radiant heating and cooling system is to satisfy thermal comfort of the occupants. ISO 11855-2, this document, provides steady-state calculation methods for determination of the heating and cooling capacity. ISO 11855-3 specifies design and dimensioning methods of radiant heating and cooling systems to ensure the heating and cooling capacity. ISO 11855-4 provides a dimensioning and calculation method to design Thermo Active Building Systems (TABS) for energy-saving purposes, since radiant heating and cooling systems can reduce energy consumption and heat source size by using renewable energy. ISO 11855-5 addresses the installation process for the system to operate as intended. ISO 11855-6 shows a proper control method of the radiant heating and cooling systems to ensure the maximum performance which was intended in the design stage when the system is actually being operated in a building. ISO 11855-7 presents a calculation method for input parameters to ISO 52031.

Building environment design — Embedded radiant heating and cooling systems —

Part 2: Determination of the design heating and cooling capacity

1 Scope

This document specifies procedures and conditions to enable the heat flux in water-based surface heating and cooling systems to be determined relative to the medium differential temperature for systems. The determination of thermal performance of water-based surface heating and cooling systems and their conformity to this document is carried out by calculation in accordance with design documents and a model. This enables a uniform assessment and calculation of water-based surface heating and cooling systems.

The surface temperature and the temperature uniformity of the heated/cooled surface, nominal heat flux between water and space, the associated nominal medium differential temperature, and the field of characteristic curves for the relationship between heat flux and the determining variables are given as the result.

This document includes a general method based on finite difference or finite element Methods and simplified calculation methods depending on position of pipes and type of building structure.

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 11855-1, *Building environment design —Embedded radiant heating and cooling systems — Part 1: Definitions, symbols, and comfort criteria*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 11855-1 apply.

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

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

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

4 Symbols

For the purposes of this document, the symbols in Table 1 apply.

Table 1 — Symbols

Symbol	Unit	Quantity
A_A	m^2	Surface of the occupied area
A_F	m^2	Surface of the heating or cooling surface area

Table 1 *(continued)*

Symbol	Unit	Quantity
A_R	m^2	Surface of the peripheral area
b_u	—	Calculation factor depending on the pipe spacing
B, B_G, B_0	W/(m²·K)	Coefficients depending on the system
D	m	External diameter of the pipe, including sheathing where used
d_a	m	External diameter of the pipe
d_i	m	Internal diameter of the pipe
d_M	m	External diameter of sheathing
c_{Wa}	kJ/(kg·K)	Specific heat capacity of water
h_t	W/(m²·K)	Total heat transfer coefficient (convection + radiation) between surface and space
$h_{A\text{-}F}$	W/(m²·K)	Total heat transfer coefficient (convection + radiation) between surface and space (floor)
$h_{A\text{-}W}$	W/(m²·K)	Total heat transfer coefficient (convection + radiation) between surface and space (wall)
$h_{A\text{-}C}$	W/(m²·K)	Total heat transfer coefficient (convection + radiation) between surface and space (ceiling)
K_H	W/(m²·K)	Equivalent heat transmission coefficient
K_{WL}	—	Parameter for heat conducting devices
k_{CL}	—	Parameter for heat conducting layer
L_{WL}	m	Width of heat conducting devices
L_{fin}	m	Width of fin (horizontal part of heat conducting device seen as a heating fin)
L_R	m	Length of installed pipes
m	—	Exponents for determination of characteristic curves
m_D	—	Exponents for determination of characteristic curves
m_u	—	Exponents for determination of characteristic curves
m_T	—	Exponents for determination of characteristic curves
m_H	kg/s	Design heating or cooling medium flow rate
n, n_G	—	Exponents
q	W/m²	Heat flux at the surface
q_A	W/m²	Heat flux in the occupied area
q_{des}	W/m²	Design heat flux
q_G	W/m²	Limit heat flux
q_N	W/m²	Nominal heat flux
q_R	W/m²	Heat flux in the peripheral area
q_u	W/m²	Outward heat flux
R_o	m²·K/W	Partial inwards heat transmission resistance of surface structure
R_u	m²·K/W	Partial outwards heat transmission resistance of surface structure
$R_{\lambda,B}$	m²·K/W	Thermal resistance of surface covering
$R_{\lambda,ins}$	m²·K/W	Thermal resistance of thermal insulation
s_h	m	In type B systems, thickness of thermal insulation from the outward edge of the insulation to the inward edge of the pipes (see Figure 2)
s_l	m	In type B systems, thickness of thermal insulation from the outward edge of the insulation to the outward edge of the pipes (see Figure 2)
s_{ins}	m	Thickness of thermal insulation
s_R	m	Pipe wall thickness
s_u	m	Thickness of the layer above the pipe

Table 1 *(continued)*

Symbol	Unit	Quantity
s_{WL}	m	Thickness of heat conducting device
S	m	Thickness of the screed (excluding the pipes in type A systems)
W	m	Pipe spacing
h	W/(m²·K)	Heat exchange coefficient
α_i	—	Parameter factors for calculation of characteristic curves
λ_{WL}	W/(m·K)	Heat conductivity of the heat diffusion device material
$\theta_{s,max}$	°C	Maximum surface temperature
$\theta_{s,min}$	°C	Minimum surface temperature
θ_i	°C	Design indoor temperature
θ_m	°C	Temperature of the heating or cooling medium
$\theta_{s,m}$	°C	Average surface temperature
θ_R	°C	Return temperature of heating or cooling medium
θ_V	°C	Supply temperature of heating or cooling medium
θ_u	°C	Indoor temperature in an adjacent space
$\Delta\theta_H$	K	Heating or cooling medium differential temperature
$\Delta\theta_{H,des}$	K	Design heating or cooling medium differential temperature
$\Delta\theta_{H,G}$	K	Limit of heating or cooling medium differential temperature
$\Delta\theta_N$	K	Nominal heating or cooling medium differential temperature
$\Delta\theta_V$	K	Heating or cooling medium differential supply temperature
$\Delta\theta_{V,des}$	K	Design heating or cooling medium differential supply temperature
λ	W/(m·K)	Thermal conductivity
σ	K	Temperature drop $\theta_V - \theta_R$
φ	—	Conversion factor for temperatures
ψ	—	Volume ratio of the attachment studs in the screed

5 Concept of the method to determine the heating and cooling capacity

A given type of surface (floor, wall, ceiling) delivers, at a given average surface temperature and indoor temperature (operative temperature θ_i), the same heat flux in any space independent of the type of embedded system. It is, therefore, possible to establish a basic formula or characteristic curve for cooling and a basic formula or characteristic curve for heating, for each of the type of surfaces (floor, wall, ceiling), independent of the type of embedded system, which is applicable to all heating and cooling surfaces (see Clause 6).

Two methods are included in this document:

— simplified calculation methods depending on the type of system (see Clause 7);

— finite element method and finite difference method (see Clause 8).

Different simplified calculation methods are included in Clause 7 for calculation of the surface temperature (average, maximum and minimum temperature) depending on the system construction (type of pipe, pipe diameter, pipe distance, mounting of pipe, heat conducting devices, distribution layer) and construction of the floor/wall/ceiling [covering, insulation layer, trapped air layer (Annex E), etc.]. The simplified calculation methods are specific for the given type of system, and the boundary conditions listed in Clause 7 shall be met. In the calculation report, it shall be clearly stated which calculation method has been applied.

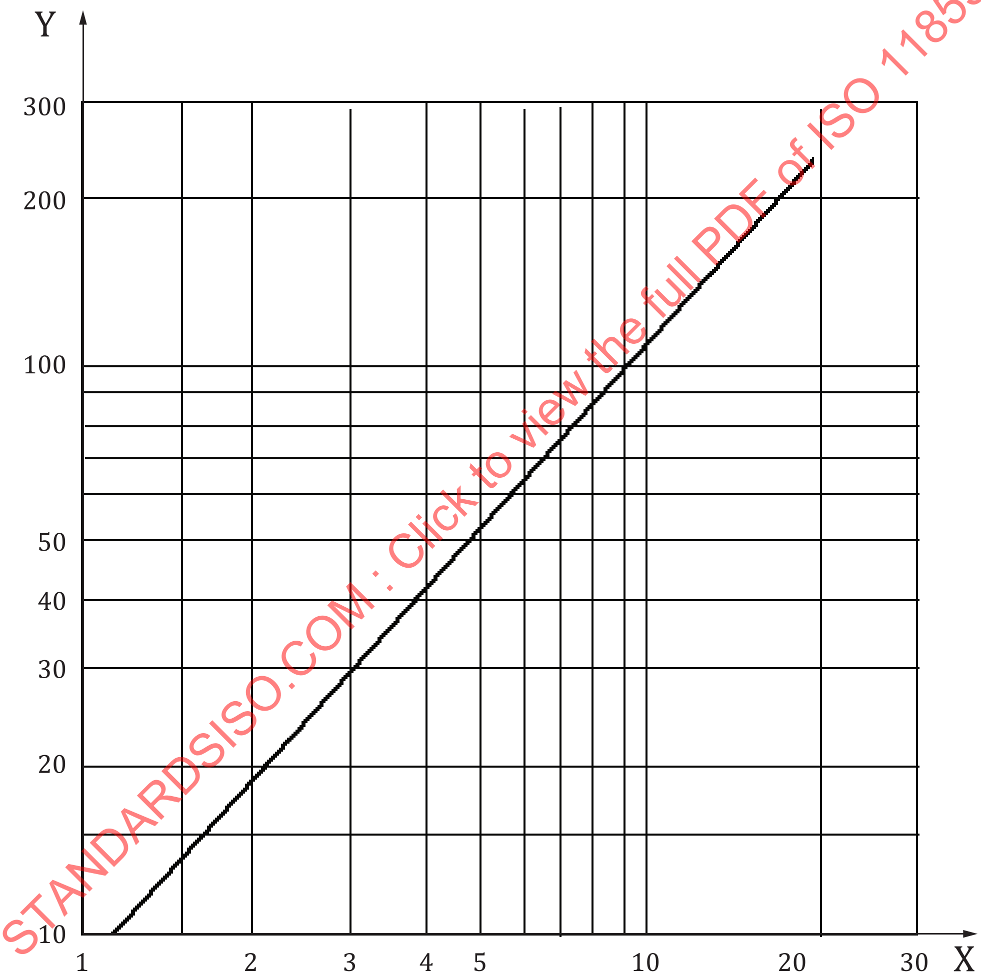
In case a simplified calculation method is not available for a given type of system, either a basic calculation using two or three dimensional finite element or finite difference method can be applied (see Clause 8 and Annex D).

NOTE In addition, laboratory testing (for example, EN 1264) can be applied.

Based on the calculated average surface temperature at given combinations of medium (water) temperature and space temperature, it is possible to determine the steady state heating and cooling capacity (see Clause 9).

6 Heat exchange coefficient between surface and space

The relationship between the heat flux and mean differential surface temperature [see Figure 1 and Formulae (1) to (4)] depends on the type of surface (floor, wall, ceiling) and whether the temperature of the surface is lower (cooling) or higher (heating) than the space temperature.



Key

X mean differential surface temperature ($\theta_{s,m} - \theta_i$) in K

Y heat flux q (W/m^2)

Figure 1 — Basic characteristic curve for floor heating and ceiling cooling

For floor heating and ceiling cooling in Figure 1, the heat flux q is given by:

$$q = 8{,}92\,(\theta_{S,m} - \theta_i)^{1{,}1} \quad (1)$$

where

$\theta_{S,m}$ is the average surface temperature, in °C;

θ_i is the nominal indoor operative temperature, in °C.

For other types of surface heating and cooling systems, the heat flux q is given by:

Wall heating and wall cooling:

$$q = 8\,(|\theta_{s,m} - \theta_i\,|) \quad (2)$$

Ceiling heating:

$$q = 6\,(|\theta_{s,m} - \theta_i\,|) \quad (3)$$

Floor cooling:

$$q = 7\,(|\theta_{s,m} - \theta_i\,|) \quad (4)$$

NOTE 1 Heat flux, q, is expressed in in W/m^2.

The heat transfer coefficient is combined convection and radiation.

NOTE 2 In many building system simulations using dynamic computer models, the heat transfer is often split up in a convective part (between heated/cooled surface and space air) and a radiant part (between heated/cooled surface and the surrounding surfaces or sources). The radiant heat transfer coefficient in the normal temperature range (15-30) °C can be fixed to 5,5 W/m^2·K. The convective heat transfer coefficient depends on type of surface, heating or cooling, air velocity (forced convection) or temperature difference between surface and air (natural convection).

By using the simplified calculation method in Annex A, the characteristic curves present the heat flux as a function of the difference between the heating or cooling medium temperature and the indoor temperature. For the user of Annex A, this means not to do any calculations by directly using values of heat transfer coefficients. Consequently, Annex A does not include values for such an application or special details or formulae concerning heat transfer coefficients on heating or cooling surfaces.

Thus, the values α of Table A.20 are not intended to calculate the heat flux directly. In fact, they are provided exclusively for the conversion of characteristic curves in accordance with Formula (A.33). For simplifications these calculations are based on the same heat transfer coefficient for floor cooling and ceiling heating, 6,5 W/(m^2·K).

For every surface heating and cooling system, there is a maximum allowable heat flux, the limit heat flux q_G. This is determined for a selected design indoor room temperature of θ_i (for heating, often 20 °C and for cooling, often 26 °C) at the maximum or minimum surface temperature $\theta_{F,max}$ and a temperature drop $\sigma = 0$ K.

For the calculations, the centre of the heating or cooling surface area, regardless of the type of system, is used as a reference point for $\theta_{S,max}$.

The average surface temperature, $\theta_{S,m}$, which determines the heat flux (refer to the basic characteristic curve) is linked with the maximum or minimum surface temperature: $\theta_{S,m} < \theta_{S,max}$ and $\theta_{S,m} > \theta_{S,min}$ always applies. (See Annex F for the maximal surface temperature for floor heating systems.)

The attainable value, $\theta_{S,m}$, depends not only on the type of system, but also on the operating conditions (temperature drop $\sigma = \theta_V - \theta_R$, outward heat flux q_u and heat resistance of the covering $R_{\lambda,B}$).

The following assumptions form the basis for the calculation of the heat flux:

— the heat transfer between the heated or cooled surface and the space occurs in accordance with the basic characteristic curve;

— the temperature drop is σ = 0 K. The dependence of the characteristic curve on the temperature drop is determined by using the logarithmically determined mean differential heating medium temperature $\Delta\theta_H$ [see Formula (1)];

— the turbulent pipe flow is: $\frac{m_H}{d_i} > 4\ 000 \frac{kg}{h \times m}$;

— there is no lateral heat flux;

— the heat-conducting layer of the floor heating system is thermally decoupled by thermal insulation from the structural base of the building. The thermal insulation does not need to be directly below the system.

7 Simplified calculation methods for determining heating and cooling capacity or surface temperature

Two types of simplified calculation methods can be applied according to this document:

— one method is based on a single power function product of all relevant parameters developed from the finite element method (FEM);

— another method is based on calculation of equivalent thermal resistance between the temperature of the heating or cooling medium and the surface temperature (or room temperature).

A given system construction can only be calculated with one of the simplified methods. The correct method to apply depends on the type of system, A to G (position of pipes, concrete or wooden construction) and the boundary conditions listed in Table 2.

NOTE Type A is a system with pipes embedded in the thermal diffusion layer . Type C is a system with pipes embedded in the adjustment layer.

Table 2 — Criteria for selection of simplified calculation method

Pipe position	Type of system	Figure	Boundary conditions	Reference to method
In screed Thermally decoupled from the structural base of the building by thermal insulation	A, C, H, I, J	2 a)	$W \geq 0{,}050$ m $s_u \geq 0{,}01$ m $0{,}008$ m $\leq d \leq 0{,}03$ m $s_u/\lambda_e \geq 0{,}01$	7.1 A.2.2
In insulation, conductive devices Not wooden constructions except for weight bearing and thermal diffusion layer	B	2 b)	$0{,}05$ m $\leq W \leq 0{,}45$ m $0{,}014$ m $\leq d \leq 0{,}022$ m $0{,}01$ m $\leq s_u/\lambda_e \leq 0{,}18$ m	7.1 A.2.3
Plane section system	D	2 c)		7.1, A.2.4
In concrete slab	E	4	$S_T / W \geq 0{,}3$	7.2, B.1
Capillary tubes in concrete surface	F	5	$d_a / W \leq 0{,}2$	7.2, B.2
Wooden constructions, pipes in sub floor or under sub floor, conductive devices	G	6	$\lambda_{wl} \geq 10\ \lambda$ $S_{WL\lambda} \geq 0{,}01$	7.2, Annex C

7.1 Universal single power function

The heat flux between embedded pipes (temperature of heating or cooling medium) and the space is calculated by Formula (5):

$$q = B \cdot \prod_i (a_i^{m_i}) \cdot \Delta\theta_H \quad (5)$$

where

B	is a system-dependent coefficient in W/(m²·K), this depends on the type of system;
$\prod_i (a_i^{m_i})$	is the power product, which links the parameters of the structure (surface covering, pipe spacing, pipe diameter and pipe covering).

NOTE Heat flux, q, is expressed in W/m².

This calculation method is given in Annex A for the following four types of systems:

— type A with pipes embedded in the screed or concrete (see Figure 2 and A.2.2);

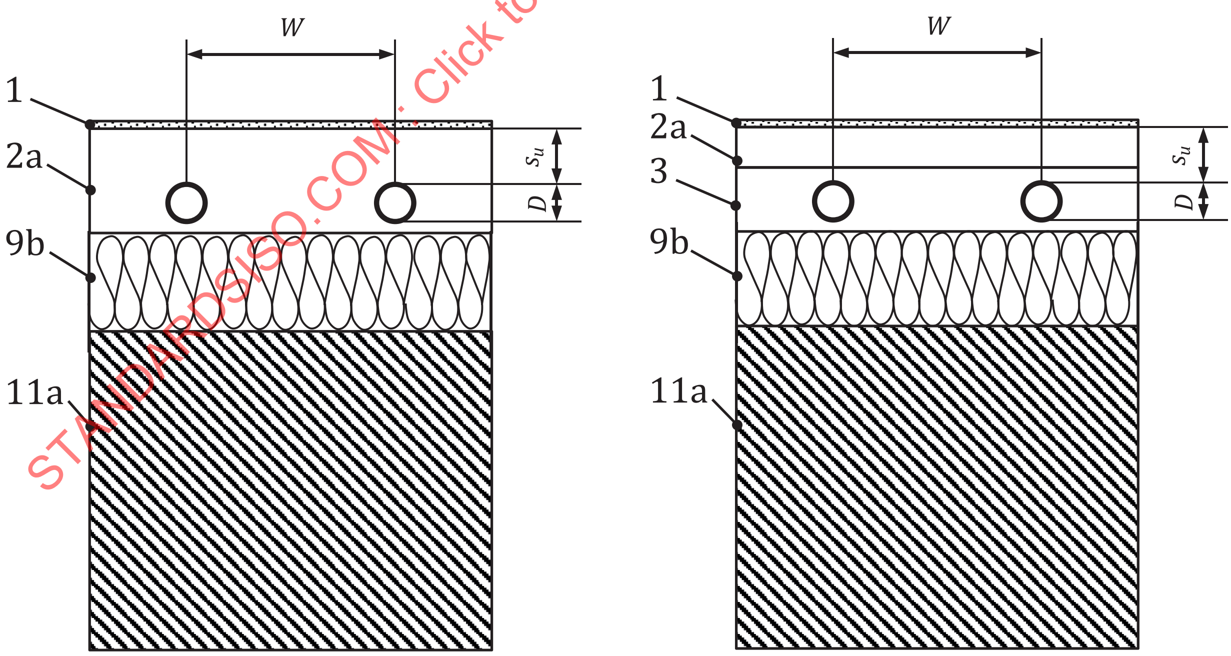
— type B with pipes embedded outside the screed (see Figure 2 and A.2.3);

— type C with pipes embedded in the screed (see Figure 2 and A.2.2);

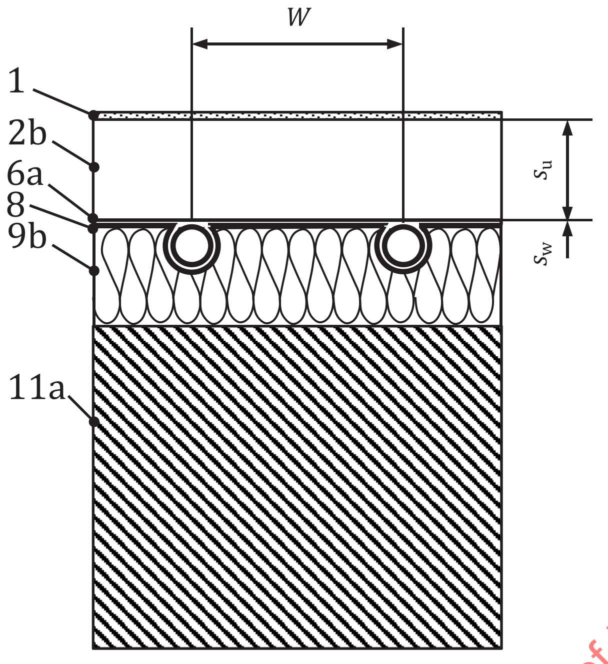
— type D plane section systems (see A.2.4).

Figure 2 shows the types as embedded in the floor, but the methods can also be applied for wall and ceiling systems with a corresponding position of the pipes.

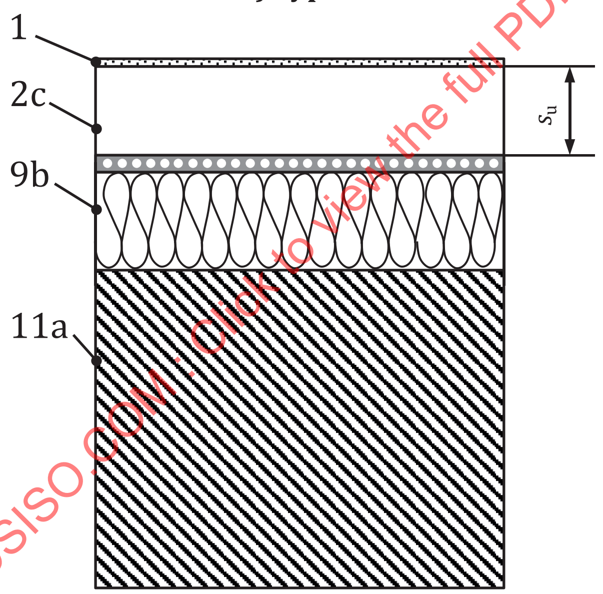
This method shall only be used for system configurations meeting the boundary conditions listed for the different types of systems in Annex A.



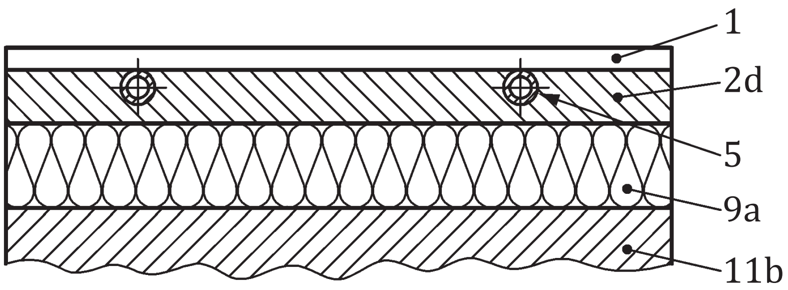
a) Type A and C



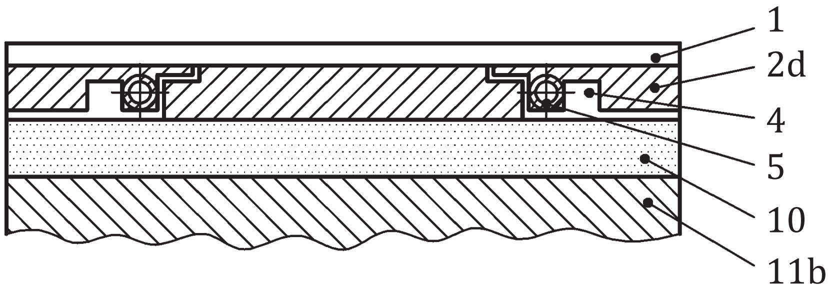
b) Type B



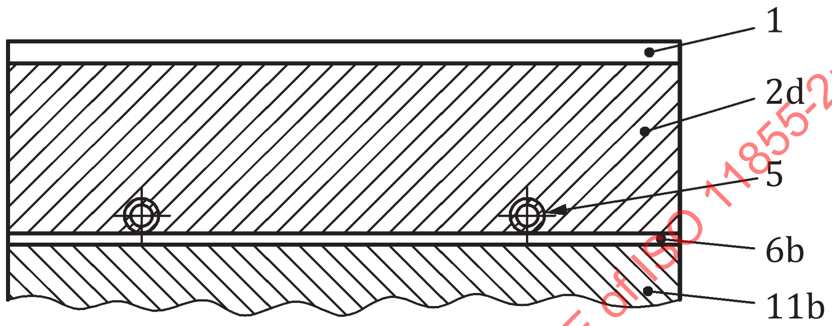
c) Type D



d) Type H



d) Type I



f) Type J

Key

1 floor covering
2a weight bearing and thermal diffusion layer (cement screed, anhydrite screed, asphalt screed)
2b weight bearing and thermal diffusion layer (cement screed, anhydrite screed, asphalt screed, wood)
2c weight bearing and thermal diffusion layer (cement screed, anhydrite screed, asphalt screed, timber)
2d weight bearing and thermal diffusion layer
3 adjustment layer (cement screed, anhydrite screed, asphalt screed)
4 profile
5 heating and cooling pipe
6a protection layer (plastic foil)
6b protection layer
7 pipe anchorage
8 heat diffusion devices
9a insulation layer
9b thermal insulation
10 adjustment layer
11a structural bearing
11b structural bearing / existing floor

Figure 2 — System types A, B, C, D, H, I and J covered by the method in Annex A

7.2 Thermal resistance methods

The heat flux between embedded pipes (temperature of heating or cooling medium) and the space or surface is calculated using thermal resistances.

The concept is shown in Figure 3.

An equivalent resistance, R_{HC}, between the heating or cooling medium to a fictive core (or heat conduction layer) at the position of the pipes is determined. This resistance includes the influence of the pipe type, pipe distance and method of pipe installation (in concrete, wooden construction, etc.). This is how a fictive core temperature is calculated. The heat transfer between this fictive layer and the surfaces, R_i and R_e (or space and neighbour space) is calculated using linear resistances (adding of resistance of the layers above and below the heat conductive layer).

The equivalent resistance of the heat conductive layer is calculated in different ways depending on the type of system.

This calculation method, using the general resistance concept, is given in Annex B for the following two types of systems:

— type E with pipes embedded in massive concrete slabs (see Figure 4 and B.1);

— type F with capillary pipes embedded in a layer at the inside surface (see Figure 5 and B.2).

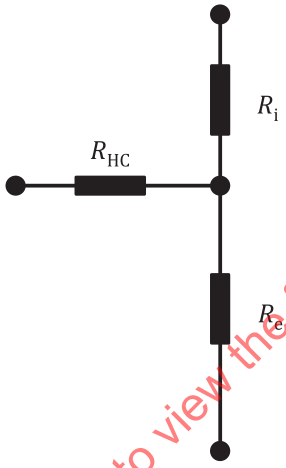
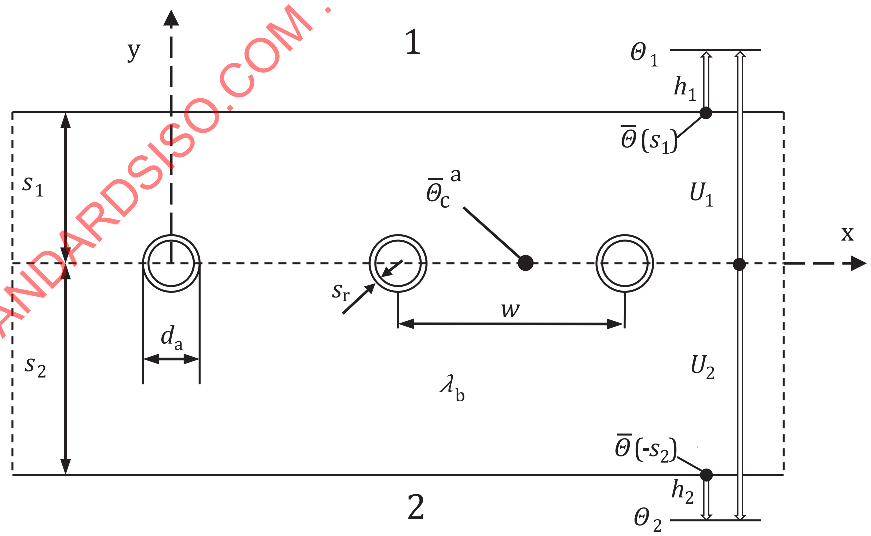


Figure 3 — Basic network of thermal resistance



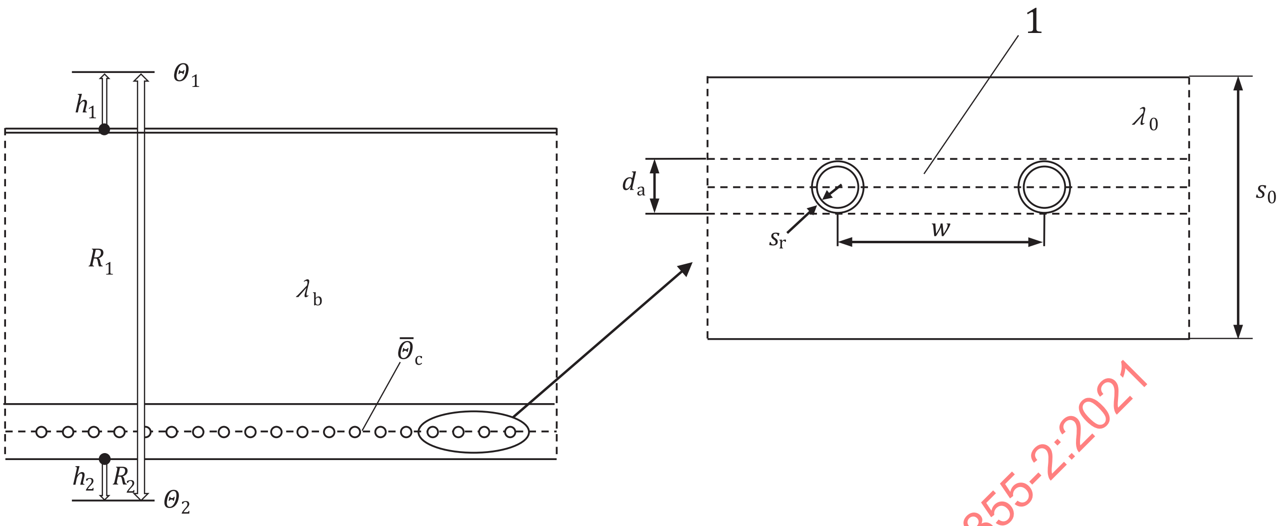
Key

1 space 1

2 space 2

a Conductive layer.

Figure 4 — Pipes embedded in a massive concrete layer, type E

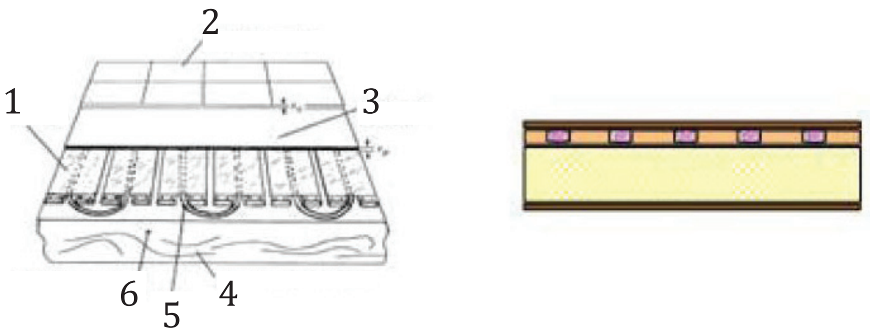


Key

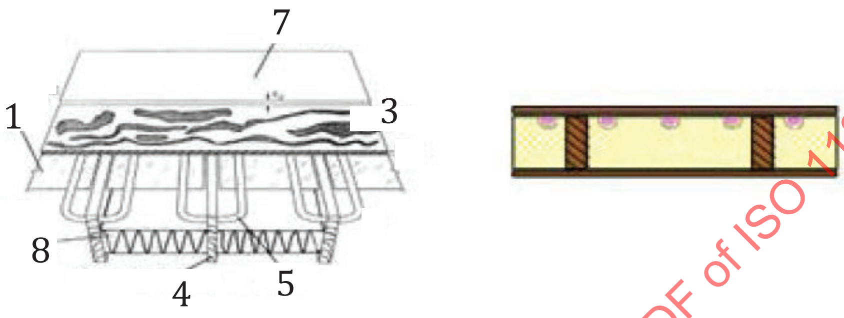
1 rib

Figure 5 — Capillary pipes embedded in a layer at the inner surface, type F

This calculation method, using the general resistance concept, is shown in Annex C for pipes embedded in wooden floor constructions using heat conducting plates (Figure 6).



Tube in subfloor



Tube under subfloor

Key

1 heat emission plates increase heat transfer where necessary
2 floor covering
3 flooring board
4 wood joist or truss
5 tube
6 insulation decreases downward heat flow
7 finished floor
8 fiberglass batt insulation with reflective surface up

Figure 6 — Pipes in wooden constructions, type G

The equivalent resistance of the conductive layer may also be determined either by calculation using finite element analysis (FEA) or finite difference methods (FDM) (see Clause 8) or by laboratory testing.

8 Use of basic calculation programmes

8.1 Basic calculation programmes

A numerical analysis by finite element method or by finite difference method shall be conducted in accordance with the state-of-the-art practice and the applicable codes and standards, in such a way that they can readily be verified. The calculation programme used shall be verified according to Annex D.

The numerical analysis may be used to calculate the heating and cooling capacity or the equivalent resistances. On basis of the equivalent resistances, the heating and cooling capacity is calculated for different temperature differences between the surface and the room.

8.2 Items to be included in a complete computation documentation

The following items shall be included in a complete computation documentation:

— representation and documentation of the structure to be analysed, by means of the technical drawings, diagrams and sketches;

— indication of the material data used as a basis and the requisite data sources;

— description of load cases used as a basis, including substantiation by codes and standards;

— description and representation of the numerical model applied, indicating the mathematical and physical basis, for example, the element type, the shape functions, number of elements, nodes and degrees of freedom;

— name, verification, if available, and origin of the computation programme;

— description of the technical assumptions, simplifications and restrictions underlying the model.

9 Calculation of the heating and cooling capacity

In some of the described calculation methods, the heating and cooling capacity are determined directly (see Annex A).

In other described calculation methods, the average surface temperature is determined and the heating and cooling capacity is calculated according to Formula (6):

$$q_{des} = h_t \left(\left|\theta_{s,m} - \theta_i\right|\right) \quad (6)$$

NOTE Design heat flux, q_{des}, is expressed in in W/m^2.

For evaluation of the performance of the system – and when calculating the total heating and cooling power needed from the energy generation system (boiler, heat exchanger, chiller, etc.) – the heat transfer at the outward (back) side shall also be considered. This heat transfer shall be regarded as a loss if the outward side is facing the outside, an un-conditioned space or another building entity, and it depends on the temperature difference between the pipe layer as well as the heat transfer resistance to and the temperature in the neighbour space or outside.

Annex A
(normative)

Calculation of the heat flux

A.1 General

The basic calculation is done for reference heating systems (see A.2).

For floor heating systems these results apply directly.

The method described in A.3 enables the conversion of these results into results for other surfaces in the room (ceiling and wall heating). The method is also applicable for all the cooling surfaces (floor, ceiling, wall cooling). This calculation method [13] is based on the results obtained in A.2.2/A.2.3 and A.2.4. The change in the surface thermal resistance $\Delta R_{\alpha}=\Delta(1/\alpha)$ influences the temperature field within the system in the same way as a change in the thermal resistance of the surface covering $\Delta R_{\lambda,B}$[13].

A.2 Reference heating systems

A.2.1 General

The heat flux q at a surface is determined by the following parameters:

— pipe spacing W;

— thickness s_u and thermal conductivity λ_E of the layer above the pipe;

— thermal conduction resistance $R_{\lambda,B}$ of covering;

— pipe external diameter $D = d_a$, including sheathing ($D = d_M$) if necessary and the thermal conductivity of the pipe λ_R and/or the sheathing λ_M. In the case of non-circular pipes, the equivalent diameter of circular pipes having the same circumference is to be calculated (the screed covering shall be used unchanged). The thickness and the thermal conduction resistance of firmly deposited barrier layers up to a thickness of 0,3 mm shall not be taken into consideration. In this case, $D = d_a$ shall be used;

— heat conducting devices, characterized by the value K_{WL} in accordance with A.3;

— contact between the pipes and the heat conducting devices or screed, characterized by the factor a_K ;

— the heat-conducting layer of the heating system is thermally decoupled by the thermal insulation from the structural base of the building.

The calculation method is limited to the boundary conditions listed in Table A.1.

Table A.1 — Criteria for selection of the simplified calculation method

Type of system	Figure	Boundary conditions	Reference to method
A, C, H, I, J	Figure A.1	$T \geq 0{,}050$ m $s_u \geq 0{,}01$ m $0{,}008 \text{ m} \leq D \leq 0{,}03$ m $s_u/\lambda_e \geq 0{,}01$	A.2.2

Table A.1 *(continued)*

Type of system	Figure	Boundary conditions	Reference to method
B	Figure A.2	$0{,}05\ \text{m} \le T \le 0{,}45\ \text{m}$ $0{,}014\ \text{m} \le D \le 0{,}022\ \text{m}$ $0{,}01\ \text{m} \le s_u/\lambda_e \le 0{,}18\ \text{m}$	A.2.3
D	Figure A.3		A.2.4

The heat flux is proportional to $(\Delta\theta_H)^n$, where the temperature difference between the heating medium and the room temperature is calculated according to Formula (A.1) and expressed in K:

$$\Delta\theta_H \frac{\theta_V - \theta_R}{\mathrm{In}\dfrac{\theta_V - \theta_i}{\theta_R - \theta_i}} \tag{A.1}$$

and where experimental and theoretical investigations of the exponent n have shown that:

$1{,}0 < n < 1{,}05$

Within the limits of the achievable accuracy, $n = 1$ is used.

The heat flux q is calculated by:

$$q = B \cdot \prod_i a_i^{m_i} \cdot \Delta\theta_H \tag{A.2}$$

where

B	is a system-dependent coefficient in W/(m²·K), this depends on the type of system;
$\prod_i (a_i^{m_i})$	is a power product which links the parameters of the structure together (see A.2.2, A.2.3 and A.2.4).

NOTE The heat flux, q, is expressed in W/m².

A distinction shall be made between systems with pipes inside the screed, systems with pipes below the screed and plane section systems. Formula (A.2) applies directly for usual constructions.

A.2.2 Systems with pipes inside the screed (type A, C, H, I, J)

For these systems (see Figure A.1), the characteristic curves are calculated by:

$$q = B \cdot a_B \cdot a_W^{m_W} \cdot a_U^{m_U} \cdot a_D^{m_D} \cdot \Delta\theta_H \tag{A.3}$$

where $B = B_0 = 6{,}7$ in W/m²·K.

NOTE 1 The heat flux, q, is expressed in W/m².

The B-values are valid for a thermal conductivity $\lambda_R = \lambda_{R,0} = 0{,}35$ W/(m·K) of the pipe and pipe wall thickness $s_R = s_{R,0} = (d_a - d_i)/2 = 0{,}002$ m.

For other materials with different heat conductivity or pipe wall thickness or for sheathed pipes, B shall be calculated in accordance with A.2.6.

For a heating screed, a value for λ_E of Table D.1 shall be used. If a different value is used, its validity shall be checked.

The surface covering factor, a_B, is in accordance with the Formula (A.4):

$$a_B = \frac{\frac{1}{\alpha} + \frac{s_{u,0}}{\lambda_{u,0}}}{\frac{1}{\alpha} + \frac{s_{u,0}}{\lambda_E} + R_{\lambda,B}} \quad \text{(A.4)}$$

where

$h_{A\text{-}F}$ = 10,8 W/(m²·K);

$\lambda_{u,0}$ = 1 W/(m·K);

$s_{u,0}$ = 0,045 m;

$R_{\lambda,B}$ is the thermal conduction resistance of the floor covering, in (m²·K)/W;

λ_E is the thermal conductivity of the screed, in W/(m·K);

a_W is the pipe spacing factor in accordance with Table A.2; $a_W = f(R_{\lambda,B})$;

a_U is the covering factor in accordance with Table A.3; $a_U = f(W, R_{\lambda,B})$;

a_D is the pipe external diameter factor in accordance with Table A.4; $a_D = f(W, R_{\lambda,B})$.

$$m_W = 1 - \frac{W}{0{,}075} \quad \text{(A.5)}$$

where 0,050 m ≤ W ≤ 0,375 m (where W is the pipe spacing).

$$m_u = 100(0{,}045 - s_u) \quad \text{(A.6)}$$

where $s_u \geq 0{,}010$ m (where s_u is the thickness of the layer above the pipe).

$$m_D = 250(D - 0{,}020) \quad \text{(A.7)}$$

applies where 0,008 m ≤ D ≤ 0,030 m (where D is the external diameter of the pipe, including sheathing where used).

Formulae (A.4) to (A.7) are valid for a thickness of layer above the pipe (inward) of 0,065 m < $s_u \leq s_u^*$, where: s_u^* = 0,100 m for pipe spacing W < 0,200 m; s_u^* = 0,5 W for pipe spacing W > 0,200 m. The actual spacing W shall be used for calculation of s_u, also if W >0,375. For $s_u > s_u^*$, the equivalent heat transfer coefficient is:

$$K_H = \frac{1}{\frac{1}{K_{H, s_u = s_u^*}} + \frac{s_u - s_u^*}{\lambda_E}} \quad \text{(A.8)}$$

NOTE 2 The heat transfer coefficient, K_H, is expressed in W/(m²·K).

In Formula (A.8), $K_{H, s_u = s_u^*}$ is the power product from Formula (A.3), calculated for a covering s_u^* above the pipe.

The heat flux is calculated according to Formula (A.9):

$$q = K_H \cdot \Delta\theta_H \tag{A.9}$$

For pipe spacing $W > 0{,}375$ m, the heat flux is approximated by Formula (A.10):

$$q = q_{0,375} \cdot \frac{0{,}375}{W} \tag{A.10}$$

where $q_{0,375}$ is the heat flux, calculated for a spacing $W = 0{,}375$ m.

NOTE 3 The heat flux, q, is expressed in W/m^2.

The limit curves are calculated in accordance with Formula (A.19) (see A.2.5).

Limitation of the method:

Position of pipes

Pipe spacing $W \geq 0{,}05$ m

Covering $s_u \geq 0{,}010$ m

Pipe diameter $0{,}008 \text{ m} \leq D \leq 0{,}03$ m

$0{,}01 \leq s_u/\lambda_E \leq 0{,}0\,792$

A.2.3 Systems with pipes below the screed or timber floor (type B)

For these systems (see Figure A.2), the variable thickness s_u of the weight bearing layer and its variable thermal conductivity λ_{WL} are represented by a factor a_U. The pipe diameter has no effect. However, the contact between the heating pipe and the heat conducting device or any other heat distribution device is an important parameter. The characteristic curve is calculated from:

$$q = B \cdot a_B \cdot a_W^{m_W} \cdot a_U \cdot a_{WL} \cdot a_K \cdot \Delta\theta_H \tag{A.11}$$

where $B = B_0 = 6{,}5$ W/(m^2·K).

NOTE The heat flux, q, is expressed in W/m^2.

The B-values are valid for a thermal conductivity $\lambda_R = \lambda_{R,0} = 0{,}35$ W/(m·K) of the pipe and a pipe wall thickness $s_R = s_{R,0} = (d_a - d_i)/2 = 0{,}002$ m.

The surface covering factor, a_B, is calculated using Formula (A.12):

$$a_B = \frac{1}{1 + B \cdot a_U \cdot a_W^{m_W} \cdot a_{WL} \cdot a_K \cdot R_{\lambda,B} \cdot \overline{f}(W)} \tag{A.12}$$

with $\overline{f}(W) = 1 + 0{,}44\sqrt{W}$

The pipe spacing factor, a_T, is in accordance with Tables A.11 - A.16, $a_T = f(s_u / \lambda_E)$.

The covering factor, a_U, is calculated in accordance with the Formula (A.13):

$$a_U = \frac{\frac{1}{\alpha} + \frac{s_{u,0}}{\lambda_{u,0}}}{\frac{1}{\alpha} + \frac{s_u}{\lambda_E}} \tag{A.13}$$

where

h = 10,8 W/(m²·K);

$\lambda_{u,0}$ = 1 W/(m·K);

$s_{u,0}$ = 0,045 m;

a_{WL} is the heat conduction device factor in accordance with Tables A.11 - A.16; $a_{WL} = f(K_{WL}, W, D)$;

a_K is the correction factor for the contact in accordance with Table A.17; $a_K = f(W)$.

$$m_W = 1 - \frac{W}{0{,}075} \text{ applies for } 0{,}050\,m \le W \le 0{,}450\,m \text{ where } W \text{ is the pipe spacing.} \quad (A.14)$$

The characteristic value K_{WL} is calculated using Formula (A.15) and it is expressed in W/(m²·K):

$$K_{WL} = \frac{s_{WL} \cdot \lambda_{WL} + b_u \cdot s_u \cdot \lambda_E}{0{,}125} \quad (A.15)$$

where

$b_u = f(W)$ is according to Table A.17;

$s_{WL} \cdot \lambda_{WL}$ is the product of the thickness and the thermal conductivity of the heat conducting material in W/K;

$s_u \cdot \lambda_E$ is the product of the thickness and the thermal conductivity of the screed in W/K.

If the width L_{WL} of the heat conducting device is smaller than the pipe spacing W, the value determined for a_{WL} according to Tables A.11 - A.16 shall be corrected to:

$$a_{WL} = a_{WL,L_{WL}=W} - (a_{WL,L_{WL}=W} - a_{WL,L_{WL}=0}) \cdot \left[1 - 3{,}2(L_{WL}/W) + 3{,}4(L_{WL}/W)^2 - 1{,}2(L_{WL}/W)^3\right]$$
(A.16)

The heat conduction device factors $a_{WL,L_{WL}=W}$ and $a_{WL,L_{WL}=0}$ shall be taken from Tables A.11 - A.16.

For L_{WL} = W, tables for the characteristic value K_{WL} are directly applicable in accordance with Formula (A.15). For L_{WL} = 0, K_{WL} shall be constituted with s_{WL} = 0.

The correction factor for the contact, a_K, takes into account the additional thermal transmission resistance caused by spot or line contact only between the pipe and the heat conducting device. This depends on the manufacturing tolerances of the pipes and conducting devices as well as on the care taken during installation and is therefore subject to fluctuations in individual cases. Table A.17, therefore, gives average values for a_K.

The limit curves are calculated in accordance with Formula (A.19) (see A.2.5).

Limitation of the method:

Position of pipes

Pipe spacing $0{,}050\,\text{m} \le W \le 0{,}450\,\text{m}$

$0{,}01 \le s_u/\lambda_E \le 0{,}0792$

A.2.4 Plane section systems

Formula (A.17) applies to surfaces fully covered with embedded heating or cooling elements (see Figure A.3):

$$q = B \cdot a_B \cdot a_W^{m_W} \cdot a_U \cdot \Delta\theta_H \qquad \text{(A.17)}$$

where $B = B_0$ =: 6,5 W/(m²·K).

NOTE The heat flux, q, is expressed in W/m².

The B-values are valid for a thermal conductivity $\lambda_R = \lambda_{R,0}$ = 0,35 W/(m·K) of the pipe and a pipe wall thickness $s_R = s_{R,0} = (d_a - d_i)/2$ = 0,002 m.

The surface covering factor, a_B is calculated using Formula (A.18):

$$a_B = \frac{1}{1 + B \cdot a_U \cdot a_T^{m_T} \cdot R_{\lambda,B}} \qquad \text{(A.18)}$$

$$a_W^{m_W} = 1{,}06$$

The covering factor, a_U, is in accordance with Formula (A.13).

A.2.5 Limits of heat flux

The procedure for the determination of the limits of the heat flux is shown in principle within Figure A.4.

The limit curve (see Figure A.4) gives the relationship between the specific thermal output and the temperature difference between the heating medium and the room for cases where the maximum permissible difference between surface temperature and indoor room temperature (9 K or 15 K respectively; (see Table A.21) is achieved.

The limit curve is calculated using the following expression in form of a product.

The limit curves are calculated by Formula (A.19):

$$q_G = \phi \cdot B_G \cdot \left[\frac{\Delta\theta_H}{\phi}\right]^{n_G} \text{ in W/m}^2 \qquad \text{(A.19)}$$

where B_G is a coefficient in accordance with:

— for type A and C systems: Tables A.5, A.6, A.7 or A.8 depending on the ratio s_u / λ_E;

— for type B systems: Table A.18;

— for plane section systems: B_G = 100 W/(m²·K);

n_G is an exponent in accordance with:

— for type A and C systems: Table A.9 or A.10 depending on the ratio s_u / λ_E;

— for type B systems: Table A.19;

— for plane section systems: n_G = 0.

φ is the factor for conversion to any values of temperatures $\theta_{F,max}$ and θ_i and is calculated according to Formula (A.20):

$$\phi = \left[\frac{\theta_{F,max} - \theta_i}{\Delta\theta_o} \right]^{1,1} \tag{A.20}$$

with $\Delta\theta_o = 9K$.

The intersection of the characteristic curve with the limit curve is calculated using Formula (A.21), expressed in K:

$$\Delta\theta_{H,G} = \phi \cdot \left[\frac{B_G}{B \cdot \prod_i a_i^{m_i}} \right]^{\frac{1}{1-n_G}} \tag{A.21}$$

The limit curves for type A and C systems, for T > 0,375 m, are calculated according to Formulae (A.22) to (A.24):

$$q_G = q_{G;0,375} \frac{0,375m}{W} \cdot f_G \tag{A.22}$$

$$\Delta\theta_{H,G} = \Delta\theta_{H,G;0,375} \cdot f_G \tag{A.23}$$

where

$q_{G;\,0,375}$	is the limit heat flux in W/m², calculated for a spacing W = 0,375 m;
$\theta_{H,\,G;\,0,375}$	is the limit temperature difference between the heating medium and the room in K, calculated for a spacing W = 0,375 m.

and

$$f_G = 1,0 \text{ for } \frac{s_u}{W} \leq 0,173$$

$$f_G = \frac{q_{G,max} - \left[q_{G,max} - q_{G,0,375} \cdot \frac{0,375}{W} \right] \cdot e^{-20\cdot(s_u/W - 0,173)^2}}{q_{G,0,375} \cdot \frac{0,375}{W}} \text{ for } \frac{s_u}{W} > 0,173 \tag{A.24}$$

where $q_{G,max}$ is the maximum permissible heat flux in accordance with Table A.21, calculated for an isothermal surface temperature distribution using the basic characteristic curve (Figure A.1), with ($\theta_{F,\,m} - \theta_i$) = ($\theta_{F,\,max} - \theta_i$).

For type B systems, Formulae (A.11) and (A.12) apply directly, when the pipe spacing W and the width of the heat diffusion device L_{WL} are the same. For L_{WL} < W, the heat flux $q_{G,\,L_{WL}=W}$ calculated in accordance with Formula (A.11), shall be corrected using Formula (A.25):

$$q_G = \frac{a_{WL}}{a_{WL,\,L_{WL}=W}} \cdot q_{G,\,L_{WL}=W} \text{ in W/m}^2 \tag{A.25}$$

where

$a_{\mathrm{WL},\,L_{\mathrm{WL}}=W}$ is the heat conduction factor in accordance with Tables A.11 - A.16 in W/(m²·K);

a_{WL} is the heat conduction factor, calculated in accordance with Formula (A.16) in W/(m²·K).

The limit temperature difference between the heating medium and the room $\Delta\theta_{\mathrm{H,G}}$ remains unchanged as with $L_{\mathrm{WT}} = W$.

For $\Delta\theta_{\mathrm{H}} = \theta_{\mathrm{F,max}} - \theta_{\mathrm{i}} = 9\,\mathrm{K}$, $\varphi = 1$ and $R_{\lambda,\mathrm{B}} = 0$, the limit heat flux q_{G} is designated as the heat flux, q_{N}, and the associated heating medium differential temperature $\Delta\theta_{\mathrm{H}}$ is designated as the nominal heating medium differential temperature, $\Delta\theta_{\mathrm{N}}$.

The maximum possible value of the heat flux, $q_{\mathrm{G,max}}$, for isothermal surface temperature distribution lies on the basic characteristic curve (see Clause 6, Figure 1, where $\theta_{\mathrm{F,m}} = \theta_{\mathrm{F,max}} = \theta_{\mathrm{S,max}}$).

If values of q_{G} higher than $q_{\mathrm{G,max}}$ are determined by Formula (A.19) due to inaccuracy of calculations, interpolations and linearization, $q_{\mathrm{G}} = q_{\mathrm{G,max}}$ shall be applied.

A.2.6 Influence of pipe material, thickness of the pipe wall and pipe sheathing on the heat flux

The values of factor B_0 given above for Formulae (A.3) and (A.11) are valid for a pipe thermal conductivity $\lambda_{\mathrm{R},0}$ = 0,35 W/(m·K), a wall thickness $s_{\mathrm{R},0}$ = 0,002 m and a heat transfer coefficient inside the pipe according to turbulent tube flow α_{turb} = 2 200 W/(m²·K). For other materials (see Table E.1) with a thermal conductivity of the pipe material λ_{R} or other wall thickness s_{R}, the factor B shall be determined by:

$$\frac{1}{B}=\frac{1}{B_0}+\frac{1{,}1}{\pi}\cdot\prod_i\left(a_i^{m_i}\right)\cdot W\cdot\left[\frac{1}{2\lambda_{\mathrm{R}}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R}}}-\frac{1}{2\lambda_{\mathrm{R},0}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R},0}}\right] \tag{A.26}$$

If the pipe has an additional sheathing with an external diameter d_{M}, an internal diameter d_{a} and a thermal conductivity of the sheathing λ_{M}, the following formulae apply:

$$\frac{1}{B}=\frac{1}{B_0}+\frac{1{,}1}{\pi}\cdot\prod_i\left(a_i^{m_i}\right)\cdot W\cdot\left[\frac{1}{2\lambda_{\mathrm{M}}}\ln\frac{d_{\mathrm{M}}}{d_{\mathrm{a}}}+\frac{1}{2\lambda_{\mathrm{R}}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R}}}-\frac{1}{2\lambda_{\mathrm{R},0}}\ln\frac{d_{\mathrm{M}}}{d_{\mathrm{M}}-2s_{\mathrm{R},0}}\right] \tag{A.27}$$

Where firmly deposited layers exist, the conversion of the factors need not be considered for thickness ≤ 0,3 mm. In this case, Formula (A.26) shall be used. In cases with air gaps within the sheathing, Formula (A.27) only applies if a valid average value λ_{M} including the air gaps is available.

Within the range of turbulent tube flows including the transition area, limited alterations of the heat transfer coefficient do not require consideration. In rare cases of application with laminar tube flow, however, a correction shall be performed. Given such a case with a laminar heat transfer coefficient α_{lam}, the following expanded version of Formulae (A.26) and (A.27) shall be used:

$$\frac{1}{B}=\frac{1}{B_0}+\frac{1{,}1}{\pi}\cdot\prod_i\left(a_i^{m_i}\right)\cdot W\cdot$$
$$\left[\frac{1}{2\lambda_{\mathrm{R}}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R}}}-\frac{1}{2\lambda_{\mathrm{R},0}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R},0}}+\frac{1}{\alpha_{\mathrm{lam}}\left(d_a-2s_{\mathrm{R}}\right)}-\frac{1}{\alpha_{\mathrm{turb}}\left(d_a-2s_{\mathrm{R},0}\right)}\right]$$

$$\frac{1}{B}=\frac{1}{B_0}+\frac{1{,}1}{\pi}\cdot\prod_i\left(a_i^{m_i}\right)\cdot W\cdot$$
$$\left[\frac{1}{2\lambda_{\mathrm{M}}}\ln\frac{d_{\mathrm{M}}}{d_{\mathrm{a}}}+\frac{1}{2\lambda_{\mathrm{R}}}\ln\frac{d_{\mathrm{a}}}{d_{\mathrm{a}}-2s_{\mathrm{R}}}-\frac{1}{2\lambda_{\mathrm{R},0}}\ln\frac{d_{\mathrm{M}}}{d_{\mathrm{M}}-2s_{\mathrm{R},0}}+\frac{1}{\alpha_{\mathrm{lam}}\left(d_a-2s_{\mathrm{R}}\right)}-\frac{1}{\alpha_{\mathrm{turb}}\left(d_{\mathrm{M}}-2s_{\mathrm{R},0}\right)}\right]$$

In these formulae, α_{turb} = 2 200 W/(m²·K) and α_{lam} = 200 W/(m²·K). Both values are average values. To characterize if the flow is turbulent or laminar, the Reynolds formula can be used $Re = w \cdot d / \nu$, where d

is the internal diameter of the pipe, w is the average velocity of the flow and ν is the kinematic viscosity of the water with an average value of $8{,}0 \times 10^{-7}$ m²/s. Laminar flow is recognized if $Re < 2\,320$ applies.

A.2.7 Thermal conductivity of screed with fixing inserts

For type A systems, the thermal conductivity in the screed is changed by inserts such as attachment studs or similar components. If their volume percent in the screed amounts to $15\ \% \geq \psi \geq 5\ \%$, an effective thermal conductivity of the component, λ_E', shall be used for calculations [see Formula (A.28) expressed in W/(m·K)]:

$$\lambda_E' = (1-\psi) \cdot \lambda_E + \psi \cdot \lambda_W \quad (A.28)$$

where

λ_E is the thermal conductivity of the screed in W/(m·K);

λ_W is the thermal conductivity of the attachment studs in W/(m·K);

ψ is the volume ratio of the attachment studs in the screed.

A.2.8 Thermal conductivity of the materials

For carrying out the calculation, the heat conductivities specified in Annex E are used. If the materials listed in Annex E are used, the values of Table E.1 shall be taken. For other materials, the heat conductivities shall be taken from effectual European Standards if available or shall be verified by a certificate prepared by an approved testing body.

A.2.9 Downward heat loss

The downward specific heat loss of floor heating systems towards rooms under the system is calculated in accordance with Formulae (A.29) to (A.31) :

$$q_U = \frac{1}{R_u} \cdot (R_o \cdot q + \theta_i - \theta_u) \quad (A.29)$$

where

q_U is the downward specific heat loss in W/m²;

q is the heat flux of the floor heating system in W/m²;

R_u is the downwards partial thermal transmission resistance of the floor structure in (m²·K)/W;

R_o is the upwards partial thermal transmission resistance of the floor structure in (m²·K)/W;

θ_i is the standard indoor room temperature of the floor heated room in °C;

θ_u is the indoor room temperature of a room under the floor heated room in °C.

$$R_o = \frac{1}{h} + R_{\lambda,B} + \frac{s_u}{\lambda_U} \quad (A.30)$$

where $1/h = 0{,}0926$ (m²·K)/W.

$$R_u = R_{\lambda,\text{ins}} + R_{\lambda,\text{ceiling}} + R_{\lambda,\text{plaster}} + R_{h,\text{ceiling}} \quad (A.31)$$

where $R_{h,\text{ceiling}} = 0{,}17$ (m²·K)/W.

In the special case of $\theta_i = \theta_U$, Formula (A.32) applies.

$$q_U = q \cdot \frac{R_o}{R_u} \tag{A.32}$$

A.3 Heating and cooling surfaces embedded in floors, ceilings and walls

The calculation method[13] is based on the results obtained in A.2.2, A.2.3 and A.2.4 of this document. The method enables the conversion of these results into results for other surfaces in the room (ceiling and wall heating). The method is also applicable for all the cooling surfaces (floor, ceiling, wall cooling). The change in the surface thermal resistance $\Delta R_\alpha = \Delta(1/\alpha)$ influences the temperature filed within the system in the same way as a change in the thermal resistance of the surface covering $\Delta R_{\lambda,B}$[13]. This is based on the assumption that all other boundary conditions are unchanged and that the dew point is not reached. This leads to Formula (A.33).

$$K_H = K_H(\Delta R_\alpha, R_{\lambda,B}) = \frac{K_{H,Floor}}{1 + \frac{\Delta R_\alpha + R_{\lambda,B}}{R^*_{\lambda,B}}\left(\frac{K_{H,Floor}}{K^*_{H,Floor}} - 1\right)} \tag{A.33}$$

NOTE K_H is expressed in W/(m²·K).

The gradient of the characteristic curve K_H [Formula (A.34)] is also referred to as equivalent heat transmission coefficient. The characteristic curve (see Figures A.5 and A.6) gives the relationship between the heat flux q and the temperature difference $\Delta\theta_H$ between the heating medium and the room (heating system) or between the room and the cooling medium (cooling system):

$$q = K_H \Delta\theta_H \tag{A.34}$$

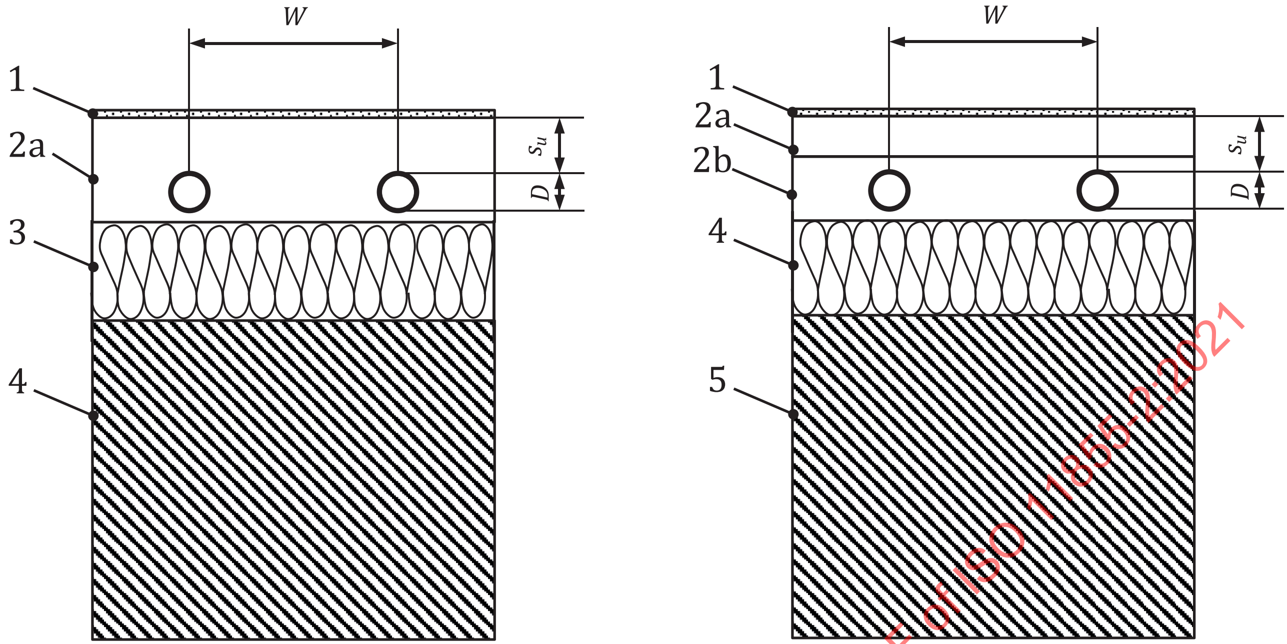
where

$K_H = K_H(\Delta R_\alpha, R_{\lambda,B})$	is the gradient of the characteristic curve [see Formula (A.34)] of the heating or cooling system which shall be calculated, with the actual thermal resistance of the covering $R_{\lambda,B} \geq 0$ and the respective value ΔR_α (see Table A.20) in W/(m²·K);
$K_{H,Floor} = K_{H,Floor}(R_{\lambda,B} = 0)$	is the gradient of the characteristic curve of the same system with the thermal resistance of the covering $R_{\lambda,B} = 0$ obtained from A.2.2/A.2.3 and A.2.4 in W/(m²·K);
$K^*_{H,Floor} = K^*_{H,Floor}(R^*_{\lambda,B})$	is the gradient of the characteristic curve of the same system with a higher thermal resistance of covering $R^*_{\lambda,B} > R_{\lambda,B}$, obtained from A.2.2/A.2.3 and A.2.4. In this annex, generally $R^*_{\lambda,B}$ = 0,15 m²·K/W applies in W/(m²·K);
ΔR_h	is the additional thermal transfer resistance to be calculated for the surface in question [see Formula (A.35) and Table A.20] in (m²·K)/W.

$$\Delta R_h = 1/\alpha - 1/10{,}8 \tag{A.35}$$

In the case of wall heating and cooling systems, the results of the calculation method described above stringently are valid only for heating or cooling surfaces which fully cover the respective wall. But the accuracy is also sufficient for cases where the wall is partially covered.

A.4 Figures and tables



Key

1 floor covering $R_{\lambda, B}$

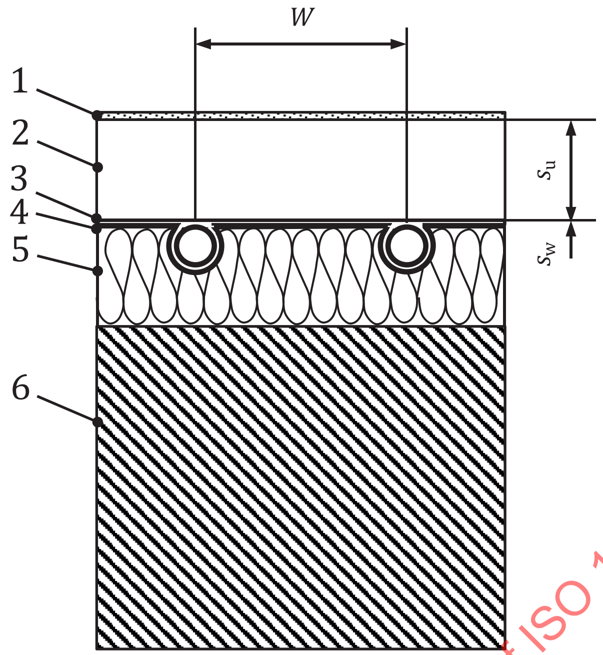
2a weight bearing and thermal diffusion layer λ_E (cement screed, anhydrite screed, asphalt screed). The thickness between the pipes and the insulation layer is in the range of 0 mm to 10 mm

2b adjustment layer (cement screed, anhydrite screed, asphalt screed)

3 thermal insulation

4 structural base

Figure A.1 — Systems with pipes inside the screed (type A and type C)



Key

1 floor covering $R_{\lambda, B}$

2 weight bearing layer λ_E (cement screed, anhydrite screed, asphalt screed, timber)

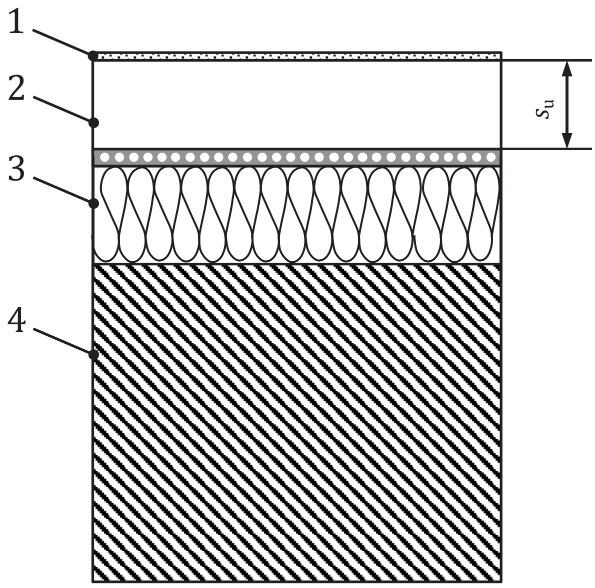
3 protection layer (plastic foil)

4 heat diffusion device

5 thermal insulation

6 structural base

Figure A.2 — System with pipes below the screed (type B)



Key

1 floor covering $R_{\lambda, B}$

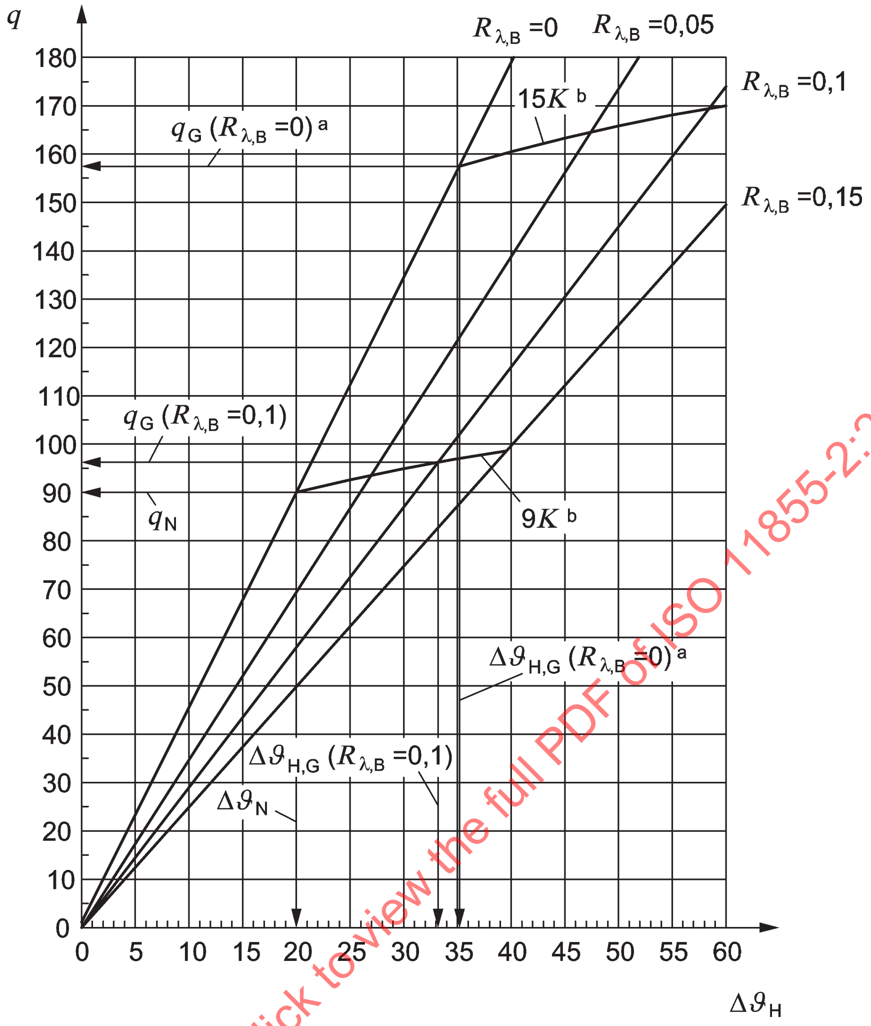
2 weight bearing and thermal diffusion layer λ_E (cement screed, anhydrite screed, asphalt screed, timber)

3 thermal insulation

4 structural base

Figure A.3 — Systems with surface elements (plane section systems, type D)

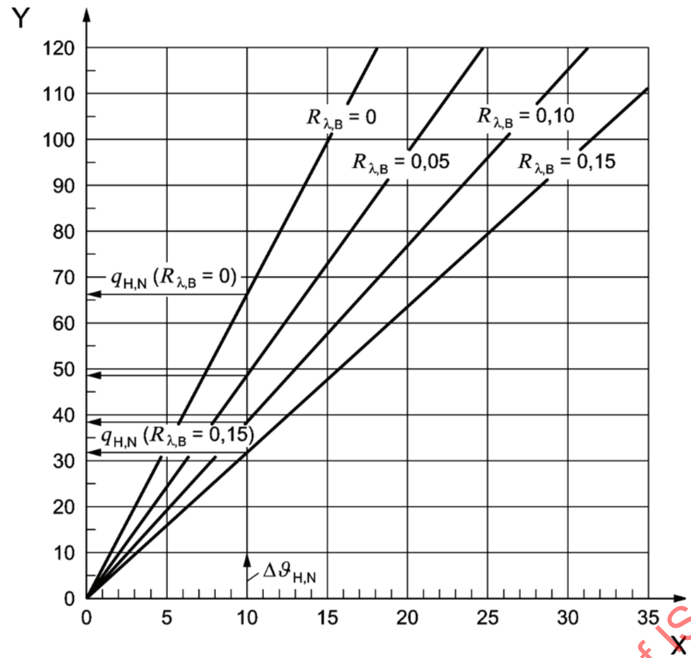
For type H, I and J see Figure 2. The names of the parameters of the calculation for the systems H, I, J are the same as in Figure A1.



Key

q	heat flux in W/m^2
$\Delta\theta_H$	temperature difference between heating medium and room in K
a	Peripheral area.
b	Limit curves.

Figure A.4 — Procedure in principle for determination of limits for heat flux

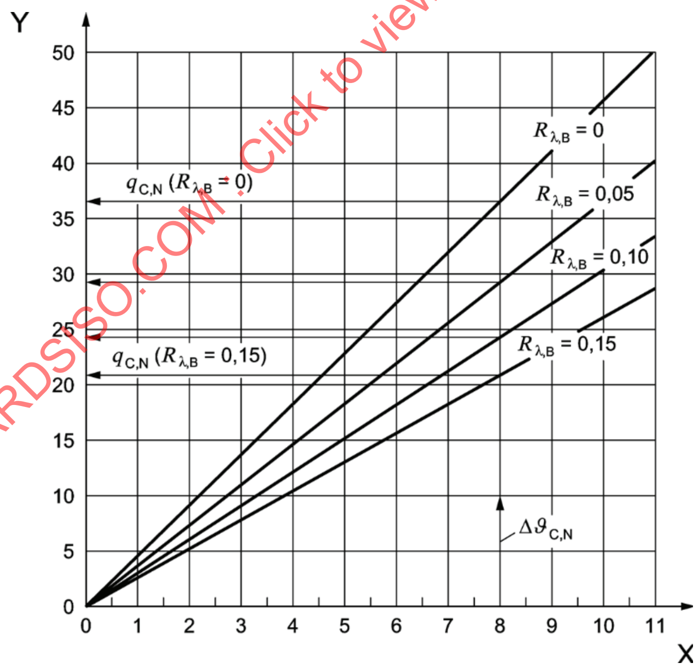


Key

Y heat flux q_H in W/m^2

X temperature difference between heating medium and room $\Delta\theta_H$ in K

Figure A.5 — Field of characteristic curves of a heating system



Key

Y heat flux q_c in W/m^2

X temperature difference between room and cooling medium $\Delta\theta_c$ in K

Figure A.6 — Field of characteristic curves of a cooling system

For all tables, intermediate values shall be interpolated with the aid of a natural cubic spline function.

Table A.2 — Pipe spacing factor a_W for types A and C, H, I and J systems

$R_{\lambda,B}$ in $(m^2 \cdot K)/W$	**0**	**0,05**	**0,10**	**0,15**
a_W	1,23	1,188	1,156	1,134

Table A.3 — Covering factor a_U depending on pipe spacing T and thermal conduction resistance of the surface covering for types A, C, H, I and J systems

T	a_u			
	$R_{\lambda,B} = 0$	$R_{\lambda,B} = 0,05$	$R_{\lambda,B} = 0,10$	$R_{\lambda,B} = 0,15$
m	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$
0,05	1,069	1,056	1,043	1,037
0,075	1,066	1,053	1,041	1,035
0,1	1,063	1,05	1,039	1,033 5
0,15	1,057	1,046	1,035	1,030 5
0,2	1,051	1,041	1,031 5	1,027 5
0,225	1,048	1,038	1,029 5	1,026
0,3	1,039 5	1,031	1,024	1,021
0,375	1,03	1,022 1	1,018 1	1,015

Table A.4 — Pipe external diameter factor a_D depending on thermal conduction resistance $R_{\lambda,B}$ of the floor covering and the pipe spacing W for types A, C, H, I and J systems

T	a_D			
	$R_{\lambda,B} = 0$	$R_{\lambda,B} = 0,05$	$R_{\lambda,B} = 0,10$	$R_{\lambda,B} = 0,15$
m	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$
0,05	1,013	1,013	1,012	1,011
0,075	1,021	1,019	1,016	1,014
0,1	1,029	1,025	1,022	1,018
0,15	1,04	1,034	1,029	1,024
0,2	1,046	1,04	1,035	1,03
0,225	1,049	1,043	1,038	1,033
0,3	1,053	1,049	1,044	1,039
0,375	1,056	1,051	1,046	1,042

Table A.5 — Coefficient B_G, depending on the ratio $s_u/\lambda_E$for $s_u/\lambda_E \le 0,079\,2$ and on the pipe spacing T for systems with pipes installed inside the screed (type A, C, H, I and J)

T	B_G								
	$\frac{s_u}{\lambda} = 0,01$	$\frac{s_u}{\lambda} = 0,020\,8$	$\frac{s_u}{\lambda} = 0,029\,2$	$\frac{s_u}{\lambda} = 0,037\,5$	$\frac{s_u}{\lambda} = 0,045\,8$	$\frac{s_u}{\lambda} = 0,054\,2$	$\frac{s_u}{\lambda} = 0,062\,5$	$\frac{s_u}{\lambda} = 0,070\,8$	$\frac{s_u}{\lambda} = 0,079\,2$
m	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$	$m^2 \cdot K/W$
0,05	85,0	91,5	96,8	100	100	100	100	100	100
0,075	75,3	83,5	89,9	96,3	99,5	100	100	100	100
0,1	66,0	75,4	82,9	89,3	95,5	98,8	100	100	100
0,15	51,0	61,1	69,2	76,3	82,7	87,5	91,8	95,1	97,8
0,2	38,5	48,2	56,2	63,1	69,1	74,5	81,3	86,4	90,0

Table A.5 *(continued)*

T m	B_G $\frac{s_u}{\lambda}$ = 0,01 m²·K/W	$\frac{s_u}{\lambda}$ = 0,020 8 m²·K/W	$\frac{s_u}{\lambda}$ = 0,029 2 m²·K/W	$\frac{s_u}{\lambda}$ = 0,037 5 m²·K/W	$\frac{s_u}{\lambda}$ = 0,045 8 m²·K/W	$\frac{s_u}{\lambda}$ = 0,054 2 m²·K/W	$\frac{s_u}{\lambda}$ = 0,062 5 m²·K/W	$\frac{s_u}{\lambda}$ = 0,070 8 m²·K/W	$\frac{s_u}{\lambda}$ = 0,079 2 m²·K/W
0,225	33,0	42,5	49,5	56,5	62	67,5	75,3	81,6	86,1
0,3	20,5	26,8	31,6	36,4	41,5	47,5	57,5	65,3	72,4
0,375	11,5	13,7	15,5	18,2	21,5	27,5	40,0	49,1	58,3

Table A.6 — Coefficient B_G, depending on the ratio s_u/W for s_u/λ_E > 0,079 2 for systems with pipes installed inside the screed (type A, C, H, I and J)

s_u / W	B_G in W/(m²·K)
0,173	27,5
0,20	40,0
0,25	57,5
0,30	69,5
0,35	78,2
0,40	84,4
0,45	88,3
0,50	91,6
0,55	94,0
0,60	96,3
0,65	98,6
0,70	99,8
>0,70	100

Table A.7 — Exponent n_G, depending on the ratio s_u/λ_E for s_u/λ_E ≤ 0,079 2 and on the pipe spacing W for systems with pipes installed inside the screed (type A, C, H, I and J)

T m	n_G s_u/λ_E = 0,01 m²·K/W	s_u/λ_E = 0,020 8 m²·K/W	s_u/λ_E = 0,029 2 m²·K/W	s_u/λ_E = 0,037 5 m²·K/W	s_u/λ_E = 0,045 8 m²·K/W	s_u/λ_E = 0,054 2 m²·K/W	s_u/λ_E = 0,062 5 m²·K/W	s_u/λ_E = 0,070 8 m²·K/W	s_u/λ_E = 0,079 2 m²·K/W
0,05	0,008	0,005	0,002	0	0	0	0	0	0
0,075	0,024	0,021	0,018	0,011	0,002	0	0	0	0
0,1	0,046	0,043	0,041	0,033	0,014	0,005	0	0	0
0,15	0,088	0,085	0,082	0,076	0,055	0,038	0,024	0,014	0,006
0,2	0,131	0,13	0,129	0,123	0,105	0,083	0,057	0,040	0,028
0,225	0,155	0,154	0,153	0,146	0,13	0,11	0,077	0,056	0,041
0,262 5	0,197	0,196	0,196	0,19	0,173	0,15	0,110	0,083	0,062
0,3	0,254	0,253	0,253	0,245	0,228	0,195	0,145	0,114	0,086
0,337 5	0,322	0,321	0,321	0,31	0,293	0,260	0,187	0,148	0,115
0,375	0,422	0,421	0,421	0,405	0,385	0,325	0,230	0,183	0,142

Table A.8 — Exponent n_G, depending on the ratio s_u/W for s_u/λ_E > 0,079 2 for systems with pipes installed inside the screed (type A, C, H, I and J)

s_u / W	n_G
0,173	0,320
0,20	0,230
0,25	0,145
0,30	0,097
0,35	0,067
0,40	0,048
0,45	0,033
0,50	0,023
0,55	0,015
0,60	0,009
0,65	0,005
0,70	0,002
>0,70	0

Table A.9 — Pipe spacing factor a_W for type B systems

s_u / λ_E in $(m^2 \cdot K)/W$	**0,01**	**0,02**	**0,03**	**0,04**	**0,05**	**0,06**	**0,08**	**0,1**	**0,15**	**0,18**
a_W	1,103	1,1	1,097	1,093	1,091	1,088	1,082	1,075	1,064	1,059

Table A.10 — Factor b_u depending on pipe spacing W for type B systems

W (m)	**0,05**	**0,075**	**0,1**	**0,15**	**0,2**	**0,225**	**0,3**	**0,375**	**0,45**
b_u	1	1	1	0,7	0,5	0,43	0,25	0,1	0

Table A.11 — Heat conduction device factor a_{WL} depending on pipe spacing W, pipe external diameter D and characteristic value K_{WL} for type B systems (K_{WL} = 0)

W	a_{WL}				
	D = 0,022	D = 0,020	D = 0,018	D = 0,016	D = 0,014
m	m	m	m	m	m
0,05	0,96	0,93	0,9	0,86	0,82
0,075	0,8	0,754	0,7	0,644	0,59
0,1	0,658	0,617	0,576	0,533	0,488
0,15	0,505	0,47	0,444	0,415	0,387
0,2	0,422	0,4	0,379	0,357	0,337
0,225	0,396	0,376	0,357	0,34	0,32
0,3	0,344	0,33	0,315	0,3	0,288
0,375	0,312	0,3	0,29	0,278	0,266
0,45	0,3	0,29	0,28	0,264	0,25

Table A.12 — Heat conduction device factor a_{WL} depending on pipe spacing W, pipe external diameter D and characteristic value K_{WL} for type B systems (K_{WL} = 0,1)

W m	a_{WL} D = 0,022 m	 D = 0,020 m	 D = 0,018 m	 D = 0,016 m	 D = 0,014 m
0,05	0,975	0,955	0,930	0,905	0,88
0,075	0,859	0,836	0,812	0,776	0,74
0,1	0,77	0,76	0,726	0,693	0,66
0,15	0,642	0,621	0,6	0,58	0,561
0,2	0,57	0,55	0,53	0,51	0,49
0,225	0,54	0,522	0,504	0,485	0,467
0,3	0,472	0,462	0,453	0,444	0,435
0,375	0,46	0,446	0,434	0,421	0,411
0,45	0,45	0,44	0,43	0,42	0,41

Table A.13 — Heat conduction device factor a_{WL} depending on pipe spacing W, pipe external diameter D and characteristic value K_{WL} for type B systems (K_{WL} = 0,2)

W m	a_{WL} D = 0,022 m	 D = 0,020 m	 D = 0,018 m	 D = 0,016 m	 D = 0,014 m
0,05	0,985	0,97	0,955	0,937	0,92
0,075	0,902	0,893	0,885	0,865	0,845
0,1	0,855	0,843	0,832	0,821	0,81
0,15	0,775	0,765	0,755	0,745	0,735
0,2	0,71	0,703	0,695	0,688	0,68
0,225	0,685	0,678	0,67	0,663	0,655
0,3	0,615	0,608	0,6	0,592	0,585
0,375	0,58	0,573	0,565	0,558	0,55
0,45	0,57	0,565	0,56	0,555	0,55

Table A.14 — Heat conduction device factor a_{WL} depending on pipe spacing W, pipe external diameter D and characteristic value K_{WL} for type B systems (K_{WL} = 0,3)

W m	a_{WL} D = 0,022 m	 D = 0,020 m	 D = 0,018 m	 D = 0,016 m	 D = 0,014 m
0,05	0,99	0,98	0,97	0,96	0,95
0,075	0,94	0,935	0,93	0,925	0,92
0,1	0,92	0,915	0,91	0,905	0,9
0,15	0,855	0,855	0,855	0,855	0,855
0,2	0,8	0,8	0,8	0,8	0,8
0,225	0,79	0,79	0,79	0,79	0,79
0,3	0,72	0,72	0,72	0,72	0,72
0,375	0,69	0,69	0,69	0,69	0,69
0,45	0,68	0,68	0,68	0,68	0,68

Table A.15 — Heat conduction device factor a_{WL} depending on pipe spacing W, pipe external diameter D and characteristic value K_{WL} for type B systems (K_{WL} = 0,4)

W m	a_{WL} D = 0,022 m	 D = 0,020 m	 D = 0,018 m	 D = 0,016 m	 D = 0,014 m
0,05	0,995	0,99	0,985	0,978	0,97
0,075	0,96	0,962	0,963	0,964	0,965
0,1	0,94	0,94	0,94	0,94	0,94
0,15	0,895	0,895	0,895	0,895	0,895
0,2	0,86	0,86	0,86	0,86	0,86
0,225	0,84	0,84	0,84	0,84	0,84
0,3	0,78	0,78	0,78	0,78	0,78
0,375	0,76	0,76	0,76	0,76	0,76
0,45	0,75	0,75	0,75	0,75	0,75

Table A.16 — Heat conduction device factor a_{WL} depending on pipe spacing W and characteristic value K_{WL} for type B systems ($K_{WL} \geq$ 0,5) (a_{WL} no longer dependent on D)

W (m)	a_{WL}						
	K_{WL} = 0,5	K_{WL} = 0,6	K_{WL} = 0,7	K_{WL} = 0,8	K_{WL} = 0,9	K_{WL} = 1,0	$K_{WL} = \infty$
0,05	0,995	0,998	1	1	1	1	1
0,075	0,979	0,984	0,99	0,995	0,998	1	1,01
0,1	0,963	0,972	0,98	0,988	0,995	1	1,02
0,15	0,924	0,945	0,96	0,974	0,99	1	1,04
0,2	0,894	0,921	0,943	0,961	0,98	1	1,06
0,225	0,88	0,908	0,934	0,955	0,975	1	1,07
0,3	0,83	0,87	0,91	0,94	0,97	1	1,09
0,375	0,815	0,86	0,90	0,93	0,97	1	1,1
0,45	0,81	0,86	0,90	0,93	0,97	1	1,1

$K_{WL}>1$

$$a_{WL} = [a_{WL}]_{K_{WL}=\infty} - \left([a_{WL}]_{K_{WL}=\infty} - [a_{WL}]_{K_{WL}=0}\right)\left[\frac{[a_{WL}]_{K_{WL}=\infty} - 1}{[a_{WL}]_{K_{WL}=\infty} - [a_{WL}]_{K_{WL}=0}}\right]^{K_{WL}}$$

Table A.17 — Correction factor for the contact a_K for type B systems

W (m)	**0,05**	**0,075**	**0,1**	**0,15**	**0,2**	**0,225**	**0,3**	**0,375**	**0,45**
a_K	1	0,99	0,98	0,95	0,92	0,9	0,82	0,72	0,60

Table A.18 — Coefficient B_G depending on K_{WL} and pipe spacing W for type B systems

K_{WL}	B_G								
	W = 0,05 m	W = 0,075 m	W = 0,1 m	W = 0,15 m	W = 0,2 m	W = 0,225 m	W = 0,3 m	W = 0,375 m	W = 0,45 m
0,1	92	86,7	79,4	64,8	50,8	45,8	27,5	9,9	0
0,2	93,1	88	81,3	67,5	54,2	49	31,8	15,8	2,4
0,3	94,2	89,5	83,3	70,2	57,6	52,5	36	21,3	7,0
0,4	95,4	90,7	85,2	72,9	60,8	56	40,2	25,7	11,9

Table A.18 *(continued)*

K_{WL}	B_G								
	W = 0,05 m	W = 0,075 m	W = 0,1 m	W = 0,15 m	W = 0,2 m	W = 0,225 m	W = 0,3 m	W = 0,375 m	W = 0,45 m
0,5	96,6	92,1	87,2	75,6	64,1	59,3	44,4	30	16,6
0,6	97,8	93,7	89,2	78,3	67,3	62,6	48,6	34,1	21,1
0,7	98,7	95	91	81	70,6	66,3	52,8	38,5	25,5
0,8	99,3	96,3	93	83,7	74	69,7	57	42,8	29,6
0,9	99,8	97,7	95	86,3	77,2	73	61,2	47	33,6
1,0	100	98,5	96,5	89	80,7	76,6	65,4	51,4	37,3
1,1	100	99,3	97,8	91,5	84	80	69,4	55,6	40,9
1,2	100	99,6	98,5	93,8	87,2	83,3	73,2	59,8	44,3
1,3	100	99,8	99,3	95,8	90	86,3	76,6	63,8	47,5
1,4	100	100	99,8	97,5	92,5	89	80	67,3	50,5
1,5	100	100	100	98,6	94,8	91,7	83	71	53,4

Table A.19 — Exponent n_G depending on K_{WL} and pipe spacing W for type B systems

K_{WL}	n_G								
	W = 0,05 m	W = 0,075 m	W = 0,1 m	W = 0,15 m	W = 0,2 m	W = 0,225 m	W = 0,3 m	W = 0,375 m	W = 0,45 m
0,1	0,002 9	0,017	0,032	0,067	0,122	0,151	0,235	0,333	1
0,2	0,002 4	0,015	0,027	0,055	0,097	0,120	0,184	0,288	0,725
0,3	0,002 1	0,013	0,024	0,048	0,086	0,104	0,169	0,256	0,482
0,4	0,001 8	0,012	0,022	0,044	0,08	0,095	0,156	0,228	0,38
0,5	0,001 5	0,011	0,02	0,04	0,074	0,088	0,143	0,204	0,31
0,6	0,001 2	0,009 9	0,018	0,037	0,067	0,082	0,131	0,183	0,25
0,7	0,000 9	0,008 7	0,016	0,033	0,061	0,074	0,118	0,162	0,21
0,8	0,006	0,007 4	0,014	0,03	0,055	0,067	0,106	0,144	0,187
0,9	0,000 3	0,006 2	0,012	0,027	0,049	0,06	0,095	0,126	0,165
1,0	0	0,005	0,01	0,024	0,044	0,053	0,083	0,11	0,143
1,1	0	0,003 8	0,008	0,021	0,038	0,046	0,072	0,096	0,121
1,2	0	0,002 5	0,006	0,018	0,032	0,038	0,063	0,084	0,107
1,3	0	0,001 2	0,004	0,015	0,027	0,034	0,054	0,073	0,093
1,4	0	0	0,002	0,012	0,022	0,029	0,047	0,063	0,080
1,5	0	0	0	0,009	0,02	0,025	0,04	0,055	0,070

Table A.20 — Additional thermal transfer resistance

Case of application	h W/(m²·K)	$\Delta R = 1/h - 1/10{,}8$ (m²·K)/W
Floor heating	10,8	0,000 0
Floor cooling	6,5	0,061 3
Wall heating	8	0,032 4
Wall cooling	8	0,032 4
Ceiling heating	6,5	0,061 3

Table A.20 *(continued)*

Case of application	h W/(m²·K)	$\Delta R = 1/h - 1/10,8$ (m²·K)/W
Ceiling cooling	10,8	0,000 0

NOTE The heat transfer coefficients and the resulting resistance ae average values. They represent a combination of convective and radiation influence.

The calculation method of A.2 takes into account the heat transfer on the heating surface in accordance with the basic characteristic curve (see Clause 6, Figure 1). This curve implicates a heat transfer coefficient depending on the temperature difference between the surface and the design indoor temperature[14].

The characteristic curves determined according to this annex present the heat flux as a function of the difference between the heating or cooling medium temperature and the indoor temperature. This means for the user of the annex, not to do any calculations by directly using values of heat transfer coefficients. Consequently, this annex does not include values for such an application or special details or formulae concerning heat transfer coefficients on heating or cooling surfaces.

Thus, the values h in Table A.20 are not intended to calculate the heat flux directly. In fact, they are provided exclusively for the conversion of characteristic curves in accordance with Formula (A.33). Such a conversion shall be performed considering the temperature conditions of the respective value of the heat flux or close to these conditions. This means that, in this annex, the value α of an application has to be specified according to the respective range of temperature.

Reference [15] deals with the heat transfer between heating or cooling surfaces and the room. This publication gives special attention to the case if the operative indoor temperature [2] is the reference value of the room temperature. The "sensed" indoor temperature [14] has a homogeneous definition and is used for reference in this document (denomination: design indoor temperature). The values α of Table A.20 are specified in best compliance with the respective temperature ranges and the conclusions drawn in Reference [15].

Table A.21 — Values for $q_{G,\max}$ depending on $\theta_{F,\max}$ and θ_i

$\theta_{F,\max}$ (°C)	θ_i (°C)	$q_{G,\max}$ (W/m²)	
29	20	100	occupied area
33	24	100	bathroom and similar
35	20	175	peripheral area

Annex B
(informative)

General resistance method

B.1 General formulae

This annex outlines a basic calculation method using "linear" thermal resistances. In this way the important parameters for the heat transfer are highlighted. In addition, a clear distinction is made between the heat transfer in the structure and the heat transfer between surface and space. However, some of the equivalent resistances may be determined by finite element or finite difference methods.

The resistance network is shown in Figures B.1 and B.2.

The influences of the pipe type (diameter, wall thickness, material), pipe spacing, water flow rate and the resistance of the conductive layer are included in the virtual resistance R_t [see Formula (B.1)]:

$$R_t = R_z + R_w + R_r + R_x \tag{B.1}$$

where

R_t is the resistance between the supply temperature θ_v and the average temperature of the conductive layer $\bar{\theta}_c$ in $(m^2 \cdot K)/W$;

R_z is the fictive resistance between the supply temperature θ_v and the average temperature of the heating medium in $(m^2 \cdot K)/W$;

R_w is the resistance between the fluid and the pipe wall $(1/h_w)$ in $(m^2 \cdot K)/W$;

R_r is the resistance of the pipe wall in $(m^2 \cdot K)/W$;

R_x is the resistance between the pipe outside wall temperature and the average temperature of the conductive layer in $(m^2 \cdot K)/W$.

For steady state conditions the resistance R_t is determined by Formula (B.2):

$$R_t = \frac{1}{\dot{m}_{H,sp} \cdot c \cdot \left[1 - \exp\left(-\frac{1}{\left(R_w + R_r + R_x + \frac{1}{U_1 + U_2}\right) \cdot \dot{m}_{H,sp} \cdot c}\right)\right]} - \frac{1}{U_1 + U_2} \tag{B.2}$$

where

$\dot{m}_{H,sp}$ is the specific design heating or cooling fluid mass flow (related to the pipe covered area) in kg/s;

c is the specific heat capacity of the heating or cooling fluid;

U_i is the heat transfer coefficient between the conductive layer and the space side $i = 1$ or $i = 2$ (including the heat transfer coefficient t given in Clause 6).

The steady state heat flux into the adjacent spaces are determined by Formulae (B.3) and (B.4) (see Figure B.1):

$$\dot{q}_1 = \frac{1}{R_1 R_2 + R_1 R_t + R_2 R_t}\left[R_t(\theta_2 - \theta_1) + R_2(\theta_v - \theta_1)\right] \quad \text{(B.3)}$$

$$\dot{q}_2 = \frac{1}{R_1 R_2 + R_1 R_t + R_2 R_t}\left[R_t(\theta_1 - \theta_2) + R_1(\theta_v - \theta_2)\right] \quad \text{(B.4)}$$

where

θ_v is the supply temperature of the heating or cooling medium in °C;

$\bar{\theta}_c$ is the mean temperature of the conductive layer in °C;

$\bar{\theta}_m$ is the mean heating or cooling medium temperature in °C.

NOTE The heat flux, q, is expressed in W/m^2.

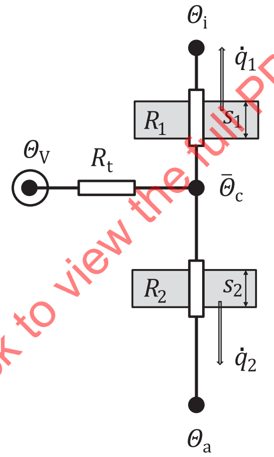


Figure B.1 — Resistance network

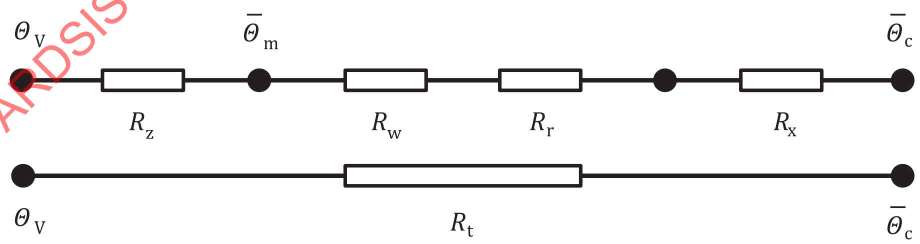
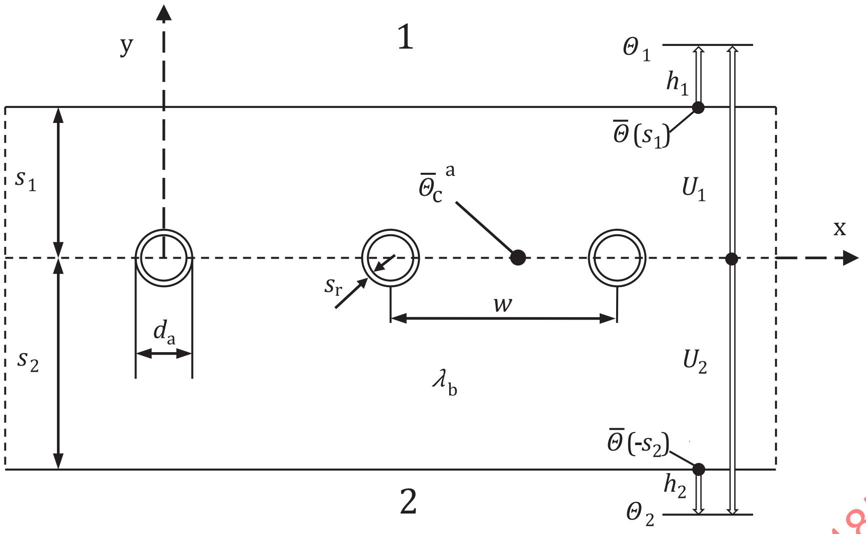


Figure B.2 — Overall resistance network

B.2 Calculation of R_t for pipes embedded in massive concrete (steady state conditions)

Dimensions and other relevant parameters for this construction are given in Figure B.3.



Key

1 space 1

2 space 2

a Conductive layer.

Figure B.3 — Pipes embedded in massive concrete slab

Formula (A.33):

$$q = K_H \cdot \Delta\theta_H$$

K_H for type E and type F is calculated according to Formula (B.5):

$$K_H = \frac{1}{(R_w + R_r + R_x + R_i)} \tag{B.5}$$

NOTE 1 The equivalent heat transmission coefficient, K_H, is expressed in W/(m²·K).

By turbulent flow of the medium inside the pipe (R_e > 2300), R is calculated according to Formula (B.6):

$$R_w = \frac{W^{0,13}}{8,0 \cdot \pi} \left(\frac{d_a - 2 \cdot s_r}{\dot{m}_{H,sp} \cdot l} \right)^{0,87} \tag{B.6}$$

The resistance of the pipe wall R is defined through Formula (B.7):

$$R_r = \frac{W \cdot \ln\left(\frac{d_a}{d_a - 2 \cdot s_r} \right)}{2 \cdot \pi \cdot \lambda_r} \tag{B.7}$$

and the resistance R between the pipe outside wall and the conductive layer can be described approximately according to Formula (B.8):

$$R_x \approx \frac{W \cdot \ln\left(\frac{W}{\pi \cdot d_a} \right)}{2 \cdot \pi \cdot \lambda_b} \tag{B.8}$$

NOTE 2 The resistance, R, is expressed in (m²·K)/W.

Limitation of method

The approximation of R is valid for:

$s_i/W > 0{,}3$ and $d_a/W < 0{,}2$

For other configurations, R_x can be determined by finite element or finite difference calculations.

The heat transfer coefficient U_i is calculated according to Formula (B.9) and expressed in W/(m²·K):

$$U_i = 1 / \left(\frac{1}{h_i} + \frac{s_i}{\lambda_b} \right) \tag{B.9}$$

The corresponding resistances are given by Formula (B.10):

$$R_i = \frac{1}{U_i} \tag{B.10}$$

where

$\dot{m}_{H,sp}$ is the specific design heating or cooling fluid mass flow (related to the pipe covered area) in kg/s;

c is the specific heat capacity of the heating or cooling fluid in J/(kg·K);

W is the pipe spacing;

d_a is the outside diameter of the pipe in m;

s_r is the pipe wall thickness in m;

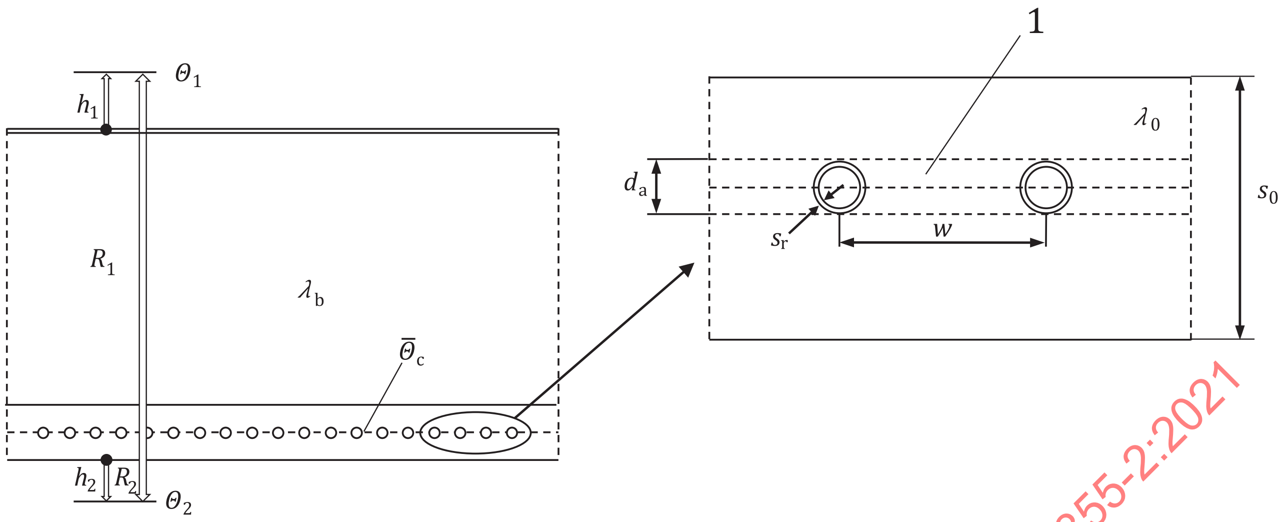
l is the length of the pipe circuit in m;

λ_b is the conductivity of the construction (concrete) in W/(m·K);

λ_r is the conductivity of the pipe wall in W/(m·K).

B.3 Calculation of R_t for capillary pipes embedded in a layer at the inner surface (steady state conditions)

Dimensions and other relevant parameters for this construction are given in Figure B.4.



Key

1 rib

Figure B.4 — Pipes embedded in layer at inside surface

For laminar flow of the medium inside the pipe (R_e < 2 300), R is calculated according to Formula (B.11):

$$R_w = \frac{W}{\pi \cdot \lambda_w} \cdot \left(49{,}03 + 4{,}17 \cdot \frac{4}{\pi} \cdot \frac{\dot{m}_{H,sp} \cdot c \cdot W}{\lambda_w} \right)^{-\frac{1}{3}} \quad \text{(B.11)}$$

Resistance of the pipe wall R_r is defined through Formula (B.12):

$$R_r = \frac{W \cdot \ln\left(\frac{d_a}{d_a - 2 \cdot s_r} \right)}{2 \cdot \pi \cdot \lambda_r} \quad \text{(B.12)}$$

and the resistance R_x between the pipe outside wall and the conductive layer can be described according to Formula (B.13):

$$R_x = \frac{W \cdot \frac{1}{3} \left(\frac{W}{\pi \cdot d_a} \right)}{2 \cdot \pi \cdot \lambda_l} \quad \text{(B.13)}$$

The heat transfer coefficients U_1 and U_2 are calculated according to Formula (B.14):

$$U_1 = 1 / \left(\frac{1}{h_1} + \frac{s_1}{\lambda_b} + \frac{s_l / 2}{\lambda_l} \right) \quad \text{(B.14)}$$

and to Formula (B.15)

$$U_2 = 1 / \left(\frac{1}{h_2} + \frac{s_l / 2}{\lambda_l} \right) \quad \text{(B.15)}$$

NOTE The heat transfer coefficient, U, is expressed in W/m^2·K.

The corresponding resistances are given by Formula (B.16):

$$R_i = \frac{1}{U_i} \tag{B.16}$$

where

$\dot{m}_{H,sp}$ is the specific design heating or cooling fluid mass flow (related to the pipe covered area) (kg/s);

c is the specific heat capacity of the heating or cooling fluid J/ (kg·K);

W is the pipe spacing;

d_a is the outside diameter of the pipe in m;

s_r is the pipe wall thickness in m;

λ_l is the conductivity of the rib layer material in W/(m·K);

λ_r is the conductivity of the pipe wall in W/(m·K);

λ_w is the conductivity of the heating or cooling fluid in W/(m·K);

λ_b is the conductivity of the construction material (concrete) in W/(m·K).

The resistance network is shown in Figure B.5.

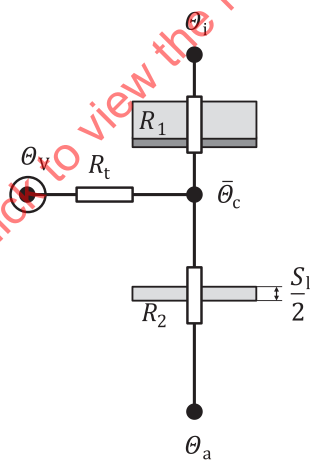


Figure B.5 — Resistance network

Annex C
(informative)

Pipes embedded in wooden construction

C.1 Field of application

The calculation method in this annex is intended for use primarily with water-based surface heating and cooling systems in conventional wooden joist floor structures and other similar lightweight structures. One characteristic of these structures is that they are built up from layers of materials having relatively low thermal conductivity, with the heat being distributed horizontally (or vertically, in walls) mainly by thermal conducting metal sheets or fins/fins with high thermal conductivity. The corresponding characteristics of other arrangements (i.e. not using heat distribution plates) can be determined by laboratory tests. This calculation method is not applicable to embedded heating and cooling systems in concrete floors, for which the method in Annex A shall be used instead.

C.2 Determination of heat transfer by calculation

C.2.1 Applicability

The calculation model employed in this document assumes that transverse conduction of heat through the floor/wall/ceiling structure depends primarily on the presence and effect of heat conducting plates. This means that the thermal conductivity of the heat conducting plates shall be considerably greater than that of the surrounding layers. See the requirements in C.2.4.4.1.

If other design arrangements are used, the characteristics shall be determined by testing as described in Annex E.

C.2.2 The calculation model — General

The heat conducting layer plays a central part in the calculation model used for heated floor structures, as shown in Figure C.1.

Heat transport through the floor structure depends on a large number of constituent components, as shown in Figure C.1, but it can be simplified to the three thermal resistances shown diagrammatically in Figure C.1:

— the thermal resistance above the heat conducting layer, from the heat conducting plate to the conditioned room, $R_{i;}$

— the thermal resistance beneath the heat conducting layer, from the heat conducting plate to a neighbour room or to the outdoor air, $R_{e;}$

— the thermal resistance from the heating medium to the heat conducting layer, R_{HC}.

These thermal resistances can be determined by calculation or by testing. The nodes shown in Figure C.1 represent the indoor temperature, the temperature in a neighbour room, ground or outside, the temperature of the pipe and the average temperature in the heat conducting layer.

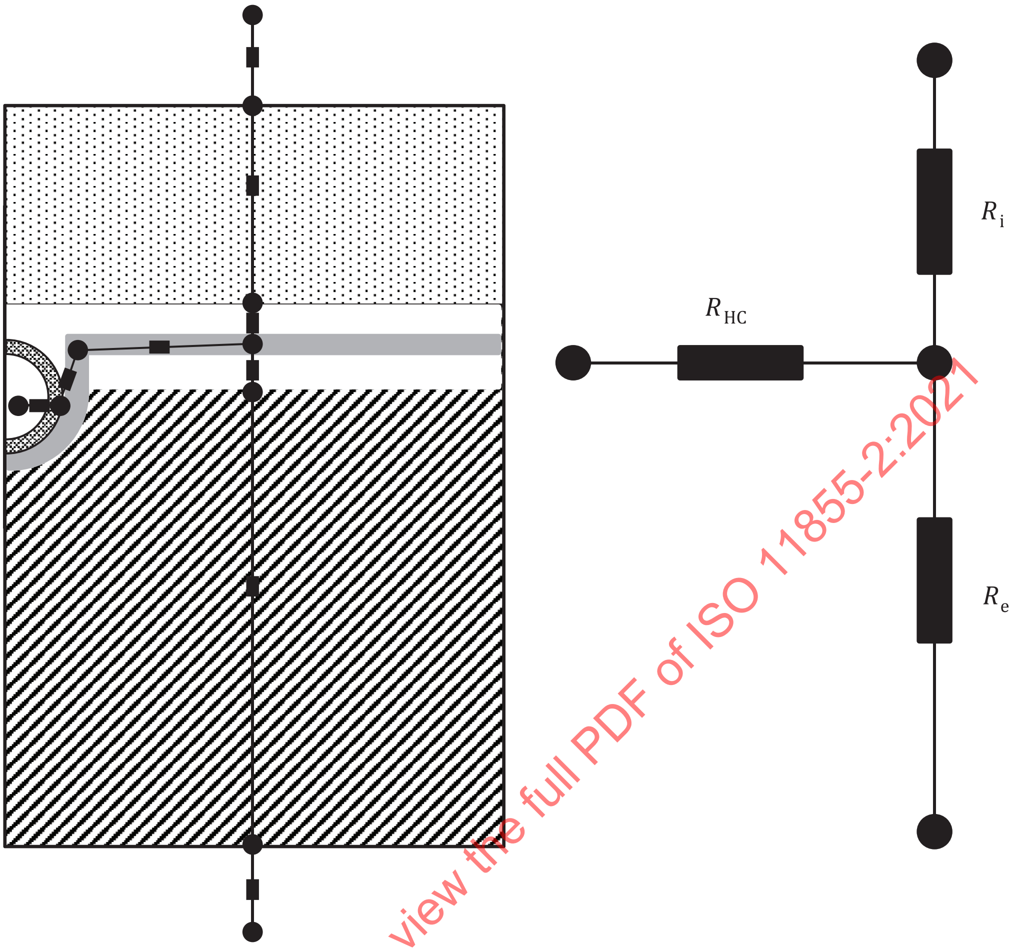


Figure C.1 — Heat transfer through the floor structure expressed as a network of thermal resistance

C.2.3 Calculation procedure for determination of equivalent heat transmission coefficient

C.2.3.1 General

This calculation procedure comprises determination of:

— maximum heat flux to the room (see C.2.3.2);

— mean temperature of the heating or cooling medium (see C.2.3.3);

— equivalent heat transmission coefficient (see C.2.3.4).

See C.2.4 for the calculation procedure for components and element characteristics.

C.2.3.2 Maximum heat flux to the room

C.2.3.2.1 Maximum or minimum permissible surface temperature

Recommended maximum or minimum surface temperatures ($\theta_{x,max}$,$\theta_{s,min}$) are given in Annex F.

C.2.3.2.2 Maximum or minimum permissible mean floor surface temperature

The maximum permissible mean floor surface temperature (in K) is given by Formula (C.1):

$$\theta_{s,m}^{max} - \theta_i = k_{CL} \cdot (\theta_{s,max,min} - \theta_i) \quad (C.1)$$

where k_{CL} is the equivalent coefficient of thermal conductivity for the heat conducting layer, in accordance with C.2.4.4.2.

C.2.3.2.3 Limitation of maximum heat flux to the room

The maximum heat flux is given in Clause 6.

C.2.3.3 Maximum/minimum permissible mean temperature of the heating or cooling medium

The maximum/minimum permissible mean temperature (in K) of the heating or cooling medium is obtained following Formula (C.2):

$$\theta_H^{max,min} = \theta_i + q_i^{max,min} \cdot \left(R_i + \frac{1}{\eta} \cdot R_{HC} \right) \quad (C.2)$$

The mean temperature of the heating medium shall never exceed this temperature.

C.2.3.4 Equivalent heat transmission coefficient

Somewhat simplified, the heat output to the room can be described by Formula (C.3):

$$q_i = K_{Hi} \cdot \Delta\theta_H \quad (C.3)$$

where

K_H	is the equivalent coefficient of thermal conductivity in W/(m²·K);
$\Delta\theta_H = \theta_H - \theta_i$	is the differential temperature of the heating or cooling medium in K.

NOTE 1 The heat flux, q, is expressed un W/m².

Calculate the equivalent coefficient of thermal conductivity towards the space using Formula (C.4):

$$K_{Hi} = 1/(R_{HC} + R_i) \quad (C.4)$$

and the equivalent coefficient of thermal conductivity towards the back-side using Formula (C.5)

$$K_{He} = 1/(R_{HC} + R_e) \quad (C.5)$$

and Formula (C.6)

$$K_{Hi} = \frac{q_i^{max,min}}{\theta_H^{max,min} - \theta_i} \quad (C.6)$$

C.2.4 Calculation procedure for components and element characteristics

C.2.4.1 General

This calculation procedure comprises determination of:

— thermal resistance above the heat conducting layer (see C.2.4.2);

— thermal resistance on the back-side of the heat conducting layer (see C.2.4.3);

— thermal resistance between the heat source and the heat conducting layer (see C.2.4.4).

See C.2.3 for the calculation procedure for determination of equivalent heat transmission coefficient.

C.2.4.2 Thermal resistance above the heat conduction layer

C.2.4.2.1 Thermal resistance of material layers

Calculate and add up the thermal resistance of the various layers of material in the upper part of the floor using Formula (C.7):

$$R_{\mathrm{o}} = \sum_{j} \frac{d_{\mathrm{j}}}{\lambda_{\mathrm{j}}} \qquad \text{(C.7)}$$

NOTE Resistance, R, is expressed in $(\mathrm{m}^2 \cdot \mathrm{K})/\mathrm{W}$.

C.2.4.2.2 Contact resistance

If the heat conducting plates are not in perfect thermal contact with the floor materials, there will be a contact resistance. For a normal design of heat conducting plates, this resistance is given by:

$$R_{\mathrm{con,i}} = 0{,}15 \ (\mathrm{m}^2 \cdot \mathrm{K})/\mathrm{W}$$

If the heat conducting plates are carefully shaped and are bonded to the floor materials, then:

$$R_{\mathrm{con,i}} = 0{,}10 \ (\mathrm{m}^2 \cdot \mathrm{K})/\mathrm{W}$$

Lower values of thermal contact resistance may be used if indicated by results of testing (according to EN 1264).

C.2.4.2.3 Boundary layer thermal resistance at the floor surface

The boundary layer thermal resistance at the floor surface is given by Formula (C.8):

$$R_{\mathrm{si}} = \frac{1}{h_{\mathrm{i}}} \qquad \text{(C.8)}$$

where h_{i} is the heat transfer coefficient, depending on the type of surface (floor $h_{\mathrm{A\text{-}F}}$, wall $h_{\mathrm{A\text{-}W}}$, ceiling $h_{\mathrm{A\text{-}C}}$) and the mode (heating or cooling), as described in Clause 6.

C.2.4.2.4 Total thermal resistance

The total thermal resistance from the heat conducting layer to the room is given by Formula (C.9):

$$R_{\mathrm{i}} = R_{\mathrm{o}} + R_{\mathrm{con,i}} + R_{\mathrm{si}} \qquad \text{(C.9)}$$