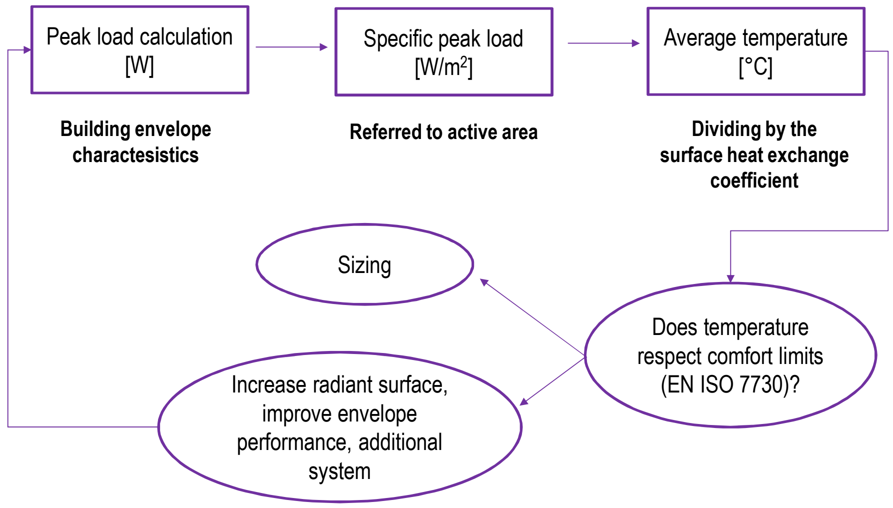
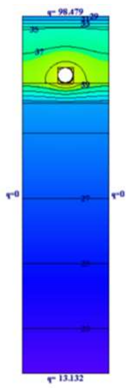
Step 1: Resume



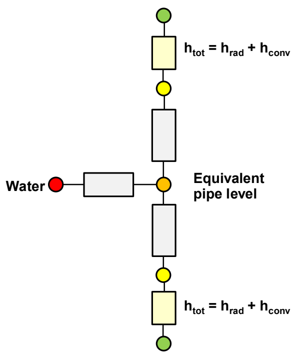
Step 2: Sizing

There are 4 methods for sizing a radiant system:

Method 1: Detailed 2-D calculation method



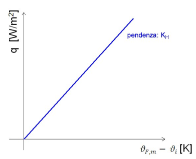
Method 2: Simplified 1-D calculation method

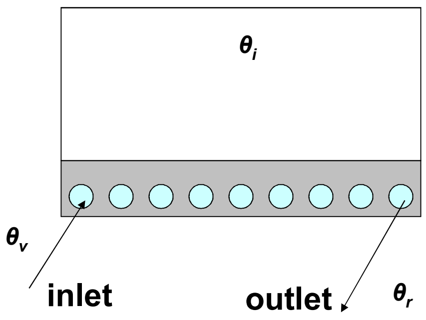


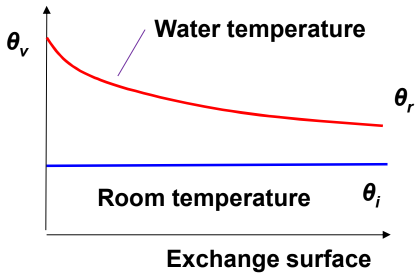
Method 3: Simplified Black-box calculation method

Geometry
Thermal properties of materials
Etc.

Method 4: Heat transfer through certified tested values

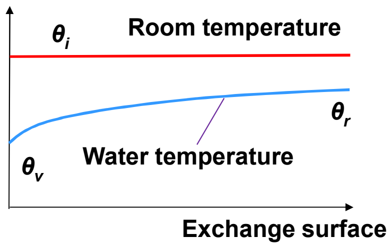






$$q_H = K_H \Delta\theta_H$$

$$\Delta\theta_H = \frac{\Delta_1 - \Delta_2}{\ln(\Delta_1/\Delta_2)}$$



$$q_C = K_C \Delta\theta_C$$

$$\Delta\theta_C = \frac{\Delta_1 - \Delta_2}{\ln(\Delta_1/\Delta_2)}$$

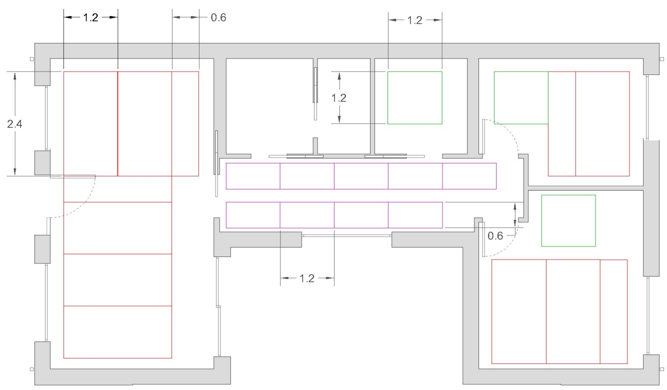
Sizing radiant walls and ceilings:

Check the available area and assume the possible amount of radiant systems, their distribution and connections.

Fix the mass flow rate/$\Delta\theta_{water}$:

$$q_H = K_H \Delta\theta_H \longrightarrow q_H = \dot{m} c_p (\theta_{v,H} - \theta_{r,H})$$

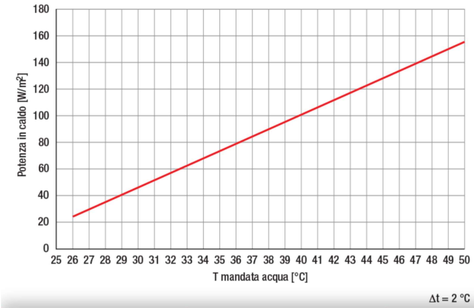
$$q_C = K_C \Delta\theta_C \longrightarrow q_C = \dot{m} c_p (\theta_{v,C} - \theta_{r,C})$$



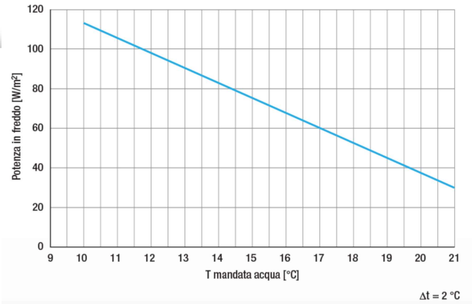
In this case the systems are prefabricated. The producer will provide the curves for K_H, K_C and the Δp as a function of the flow rates of the system

Example of K_H and K_C for a radiant ceiling provided with testing:

Same test room, used also for radiators (EN 442), but different testing methodology.



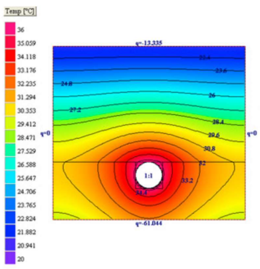
EN 14037-5 (laboratory test for radiant ceiling in heating)

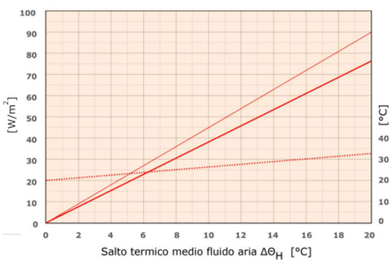


EN 14240 (laboratory test for radiant ceiling in cooling)

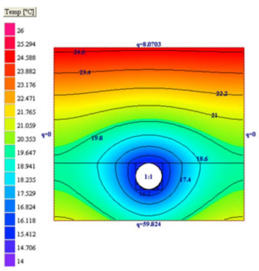
Source: Eurotherm

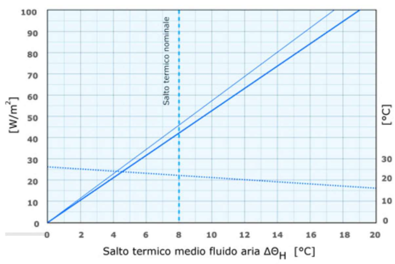
Example of K_H and K_C for a radiant ceiling calculated with a detailed 2-D method





Water power — Useful power — Surface temperature





Water power — Useful power — Surface temperature

Source: Rossato

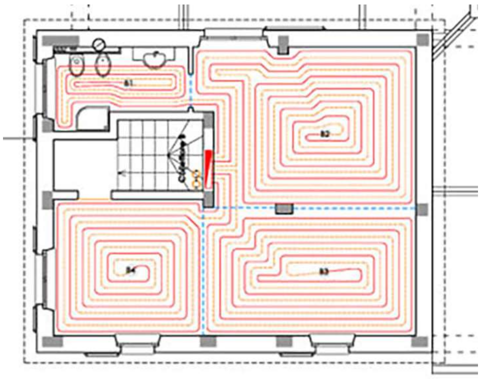
Sizing radiant floors:

Check the available area and assume the possible lay-out of the radiant floor. Define the floor covering, the type of radiant floor and concrete layer with embedded pipes. Then evaluate the

Fix the mass flow rate/$\Delta\theta_{water}$:

$$q_H = K_H \Delta\theta_H \longrightarrow q_H = \dot{m} c_p (\theta_{v,H} - \theta_{r,H})$$

$$q_C = K_C \Delta\theta_C \longrightarrow q_C = \dot{m} c_p (\theta_{v,C} - \theta_{r,C})$$



In this case the systems are prefabricated. The producer will provide the curves for K_H, K_C and the Δp as a function of the flow rates of the system

Standard EN ISO 11855

General definition of hydronic radiant systems

Depending on the position of the pipes in the building construction, hydronic radiant systems can be sorted into 4 main categories:

- **Embedded Surface Systems**: pipes embedded within the surface layer (not within the structure)
- **Thermally Active Building Systems (TABS)**: the pipes thermally coupled and embedded in the building structure (slabs, walls)
- **Capillary Surface Systems**: pipes embedded in a layer at the inner ceiling/wall surface
- **Radiant Panels**: metal pipes integrated into panels (not within the structure); heat carrier close to the surface

Focuses on embedded water based surface heating and cooling systems and TABS. Depending on construction details, this norm distinguishes 7 different types of those systems (Types A to G)

•**Type A** with pipes embedded in the screed or concrete (“wet” system)

•**Type B** with pipes embedded outside the screed (in the thermal insulation layer, “dry” system)

•**Type C** with pipes embedded in the leveling layer, above which the second screed layer is placed

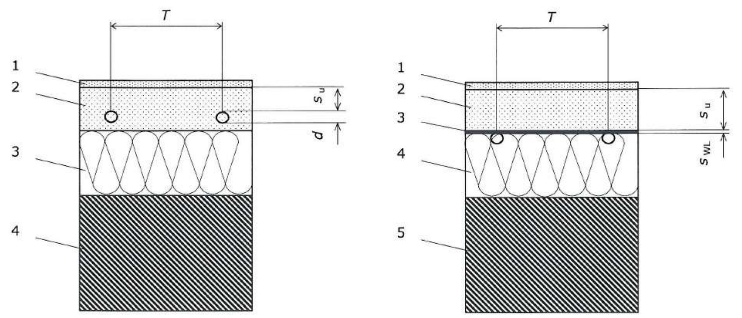
•**Type D** include plane section systems (extruded plastic / group of capillary grids)

•**Type E** with pipes embedded in a massive concrete layer

•**Type F** with capillary pipes embedded in a layer at the inner ceiling or as a separate layer in gypsum

•**Type G** with pipes embedded in a wooden floor construction

– Part 1 – definition of radiant systems



Key
1 floor covering
2 weight bearing and thermal diffusion layer (cement screed, anhydrite screed, asphalt screed)
3 thermal insulation
4 structural bearing

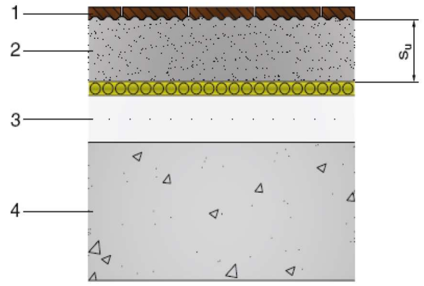
Figure 2 a) Systems of type A and C

Key
1 floor covering
2 weight bearing and thermal diffusion layer (cement screed, anhydrite screed, asphalt screed, wood)
3 heat diffusion devices
4 thermal insulation
5 structural bearing

Figure 2 b) Systems of type B

Figure 2 — Systems of type A, B and C covered by the method in EN 1264

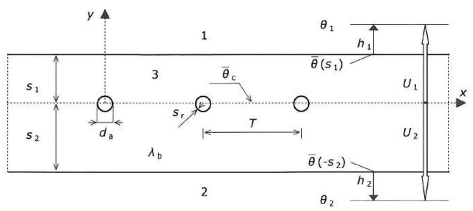
– Part 1 – definition of radiant systems



1. floor covering
2. screed
3. insulation layer
4. structural layer

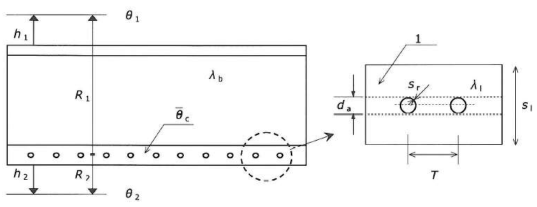
Plane section systems, type D covered by the method in EN 1264

– Part 1 – definition of radiant systems



TABS

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



Capillary systems

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

– Part 1 – definition of radiant systems

pipes embedded in wooden floor constructions using heat conducting plates, systems of type G

– Parte 1 – Determinazione delle potenze di riscaldamento e di raffrescamento

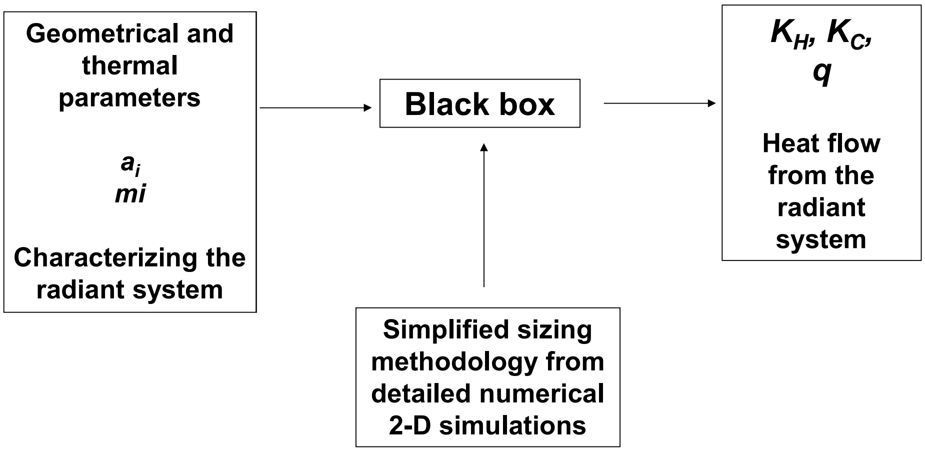
For each type of radiant system (A,B,C,D,F,G) there is a method for the calculation:

Table 2 — Criteria for selection of simplified calculation method

Pipe position	Type of system	Figure	Boundary conditions
In screed, one side loss less than or equal to 10 % of total	A, C	2a)	$T \geq 0{,}050m$ $S_u \geq 0{,}01m$ $0{,}008\ \mathrm{m} \leq d \leq 0{,}03\ \mathrm{m}$ $S_u / \lambda_e \geq 0{,}01$
In insulation, conductive devices, one side loss less than or equal to 10 % of total	B	2b)	$0{,}05 \leq T \leq 0{,}45m$ $0{,}014\ \mathrm{m} < d < 0{,}022\ \mathrm{m}$ $0{,}01 \leq S_u / \lambda_e \leq 0{,}18$
Plane section system	D		
In concrete slab	E	4	$S_T / T \geq 0{,}3$ $d_a / T \leq 0{,}2$
Capillary tubes in concrete surface	F	5	
Wooden constructions, pipes in sub floor or under sub floor, conductive devices	G	6	$\lambda_{wl} \geq 10 \cdot \lambda_{surroundingmaterial}$ $S_{WL} \cdot \lambda \geq 0{,}01$

Method according to EN 1264

Backgrounds:



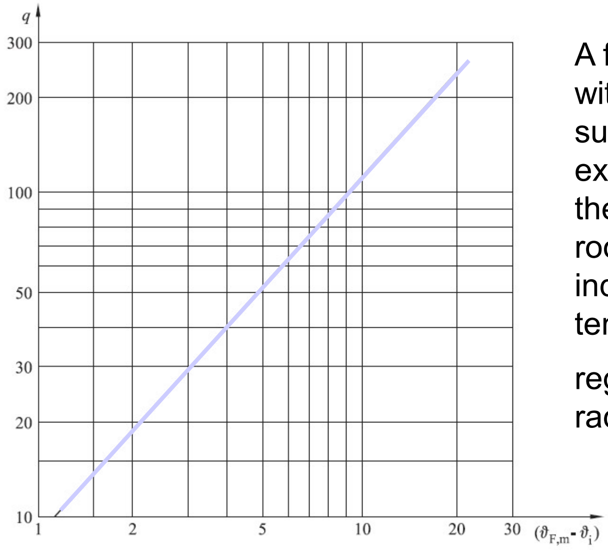
Thermal boundary conditions

- A floor heating surface with a given average surface temperature exchanges the same thermal output in any room with the same indoor room temperature $\boldsymbol{\theta_i}$.
- It is possible to give a curve of the relationship between specific thermal output and average surface temperature that is independent of the heating system and applicable to all floor heating surfaces.
- In contrast, every floor heating system has its own maximum permissible specific thermal output, $\boldsymbol{q_G}$.

$\mathbf{q_G}$ in design conditions:
$\theta_i = 20°C$; $\theta_{F\ max} = 29°C$ (for peripheral area $\theta_{F\ max} =$ 35°C) *water* temperature drop supply/return $\sigma = 0°C$,

Basic Characteristic Curve

$$q = 8.92 * (\theta_{F,m} - \theta_i)^{1.1}$$



A floor heating surface with a given average surface temperature, $\theta_{F,m}$ exchanges the same thermal output, q in any room with the same indoor room temperature, $\boldsymbol{\theta_i}$

regardless of the type of radiating system

Thermal output of the radiant floor system

- The centre of the heating surface is used as the reference point for $\boldsymbol{\theta_{F,max}}$.
- The average surface temperature $\boldsymbol{\theta_{F,m}}$, determining the specific thermal output.
- The condition $\boldsymbol{\theta_{F,m} < \theta_{F,max}}$ always applies.
- The value of $\boldsymbol{\theta_{F,m}}$ is affected by both floor heating system and operating conditions (temperature drop σ, q_u, heat resistance of the floor covering $R_{\lambda,B}$).

Conditions for the calculation

- Heat transfer of the floor is calculated in according with the basic characteristic curve.
- The temperature drop of the heat carrier fluid is equal to **σ = 0°C** (if the temperature drop is > 0°C it can be used the equation with the logarithmically determined temperature difference $\Delta\theta_H$).
- Turbulent pipe flow: ***m_H/d_i* > 4 000 kg/(h · m).**
- The lateral surfaces of the floor are adiabatics
- The heat-conducting layer of the floor heating system is thermally decoupled by thermal insulation from the structural base of the building.

- For the calculation of q the following parameters and data are required:
  - **T** → pipe spacing (pitch)
  - **s_u** → thickness of the screed
  - **λ_E** → conductivity of the layer above the pipe
  - **$R_{\lambda,B}$** → heat conduction resistance of the floor covering
  - **D = d_a** → external diameter of the pipe
  - **λ_R** → conductivity of the pipe (B type)
  - **a_K** → factor for the evaluation of the contact between the pipes and the heat diffusion devices or the screed (B type)
  - **K_{WL}** → heat diffusion devices (B type)

$$q = f[(\Delta\theta_H)^n] = f\left[\left(\frac{\theta_V - \theta_R}{ln\frac{\theta_V - \theta_i}{\theta_R - \theta_i}}\right)^n\right]$$ with n = 1.0 – 1.05

The specific thermal output is calculated with:

$$q = f[(\Delta\theta_H)^n] \quad \Rightarrow \quad q = B * \prod_i (a_i^{m_i}) * \Delta\theta_H$$

- B system-dependent coefficient [W/(m^{2}K)];
- $\prod_i (a_i^{m_i})$ power product linking the parameters of the floor construction with one another;

- A distinction shall be made between systems, where the <u>pipes are installed inside or below the screed or wood floors (A,C and B)</u>, and systems with <u>surface elements (D,</u> plane section systems). For usual constructions, the previous eq. can be apply directly.

- For systems with <u>additional devices for heat distribution</u>, for air filled hollow sections or for other components <u>influencing the heat distribution</u>, the thermal output is determined experimentally.

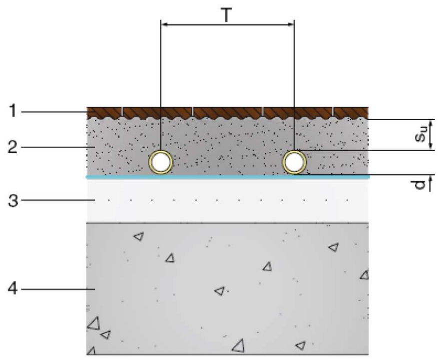
$$q = B \cdot a_B \cdot a_T^{m_T} \cdot a_u^{m_u} \cdot a_D^{m_D} \cdot \Delta\vartheta_H$$

$$q = K_H \cdot \Delta\vartheta_H$$

B → B_0 = 6.7 W/(m^{2}K) with

$\lambda_R = \lambda_{R,0}$ = 0.35 W/(mK)

$s_R = s_{R,0}$ = 0.002 m



If pipe wall thickness and conductivity of the material are different it is possible to use the next equation:

$$\frac{1}{B} = \frac{1}{B_0} + \frac{1{,}1}{\pi} * \prod_i (a_i^{m_i}) * T * \left[\frac{1}{2\lambda_R} ln \frac{d_a}{d_a - 2s_R} - \frac{1}{2\lambda_{R,0}} ln \frac{d_a}{d_a - 2s_{R,0}} - \right]$$

- a_B → is the floor covering factor

type A and type C

$$a_B = \frac{\dfrac{1}{\alpha} + \dfrac{s_{u,0}}{\lambda_{u,0}}}{\dfrac{1}{\alpha} + \dfrac{s_{u,0}}{\lambda_E} + R_{\lambda,B}}$$

α	= 10,8 W/(m^2 · K);
$\lambda_{u,0}$	= 1 W/(m · K);
$s_{u,0}$	= 0,045 m;
$R_{\lambda,B}$	is the heat conduction resistance of the floor covering, in m^2 · K/W;
λ_E	is the heat conductivity of the screed, in W/(m · K);

- a_T →is the spacing factor

$R_{\lambda,B}$ m^2 · K/W	0	0,05	0,10	0,15
a_T	1,23	1,188	1,156	1,134

$$m_T = 1 - \frac{T}{0{,}075}$$ applies where 0,050 m ≤ T ≤ 0,375 m

- a_u →is the covering factor

type A and type C

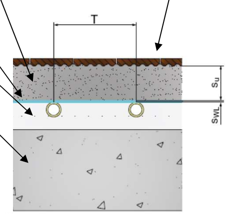
$R_{\lambda,B}$ m^2 · K/W	0	0,05	0,10	0,15
T (m)	a_u			
0,05	1,069	1,056	1,043	1,037
0,075	1,066	1,053	1,041	1,035
0,1	1,063	1,05	1,039	1,033 5
0,15	1,057	1,046	1,035	1,030 5
0,2	1,051	1,041	1,031 5	1,027 5
0,225	1,048	1,038	1,029 5	1,026
0,3	1,039 5	1,031	1,024	1,021
0,375	1,03	1,022 1	1,018 1	1,015

$m_u = 100(0{,}045 - s_u)$ applies where $s_u \geq 0{,}010$ m type A and type C

- a_D →is the pipe external diameter factor

$R_{\lambda,B}$ m² · K/W	0	0,05	0,10	0,15
T (m)	a_D			
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

$m_D = 250(D - 0{,}020)$ applies where $0{,}008 \text{ m} \le D \le 0{,}030 \text{ m}$



$$q = B \cdot a_B \cdot a_T^{m_T} \cdot a_u \cdot a_{WL} \cdot a_K \cdot \Delta\vartheta_H$$

$a_K = f(T)$ — is the correction factor for the contact

$B = B_0 = 6{,}5 \text{ W/(m}^2 \cdot \text{K)}$

a_T is the pipe spacing factor

m_T → $m_T = 1 - \dfrac{T}{0{,}075}$

a_u is the covering factor, which is calculated in accordance with the following equation:

$$a_u = \frac{\frac{1}{\alpha} + \frac{s_{u,0}}{\lambda_{u,0}}}{\frac{1}{\alpha} + \frac{s_u}{\lambda_E}}$$

α = 10,8 W/(m² · K);

$\lambda_{u,0}$ = 1 W/(m · K);

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

a_{WL} is the heat conduction factor $a_{WL} = f(K_{WL}, T, D)$

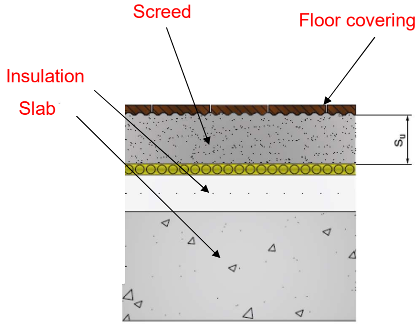
$$K_{WL} = \frac{s_{WL} \cdot \lambda_{WL} + b_u \cdot s_u \cdot \lambda_E}{0{,}125}$$

$s_{WL} \cdot \lambda_{WL} = f(T)$

a_B is the floor covering factor

$$a_B = \frac{1}{1 + B \cdot a_u \cdot a_T^{m_T} \cdot a_{WL} \cdot a_K \cdot R_{\lambda,B} \cdot f(T)}$$

$f(T) = 1 + 0{,}44\sqrt{T}$



$$q = B \cdot a_B \cdot a_T^{m_T} \cdot a_u \cdot \Delta\vartheta_H$$

where

B = B_0 = 6,5 W/(m^2 · K) and

$a_T^{m_T}$ = 1,06;

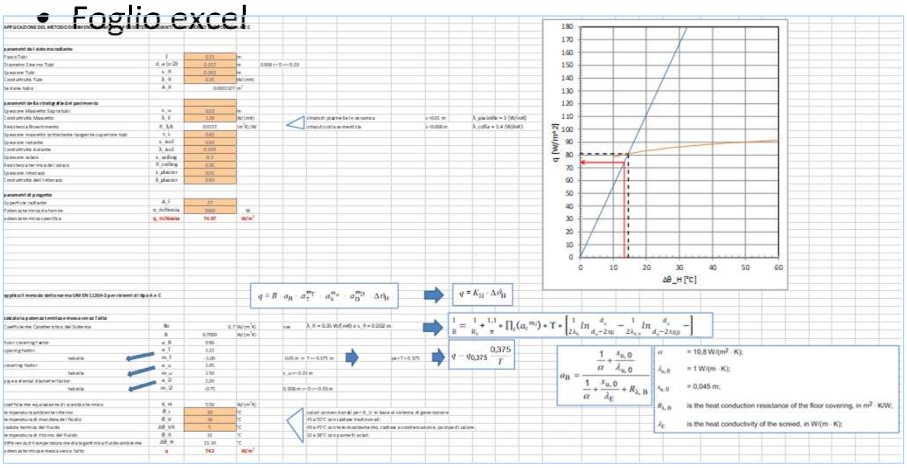
a_u is the covering factor in accordance with Equation (12);

a_B is the floor covering factor:

$$a_B = \frac{1}{1 + B \cdot a_u \cdot a_T^{m_T} \cdot R_{\lambda,B}}$$

$$a_u = \frac{\dfrac{1}{\alpha} + \dfrac{s_{u,0}}{\lambda_{u,0}}}{\dfrac{1}{\alpha} + \dfrac{s_u}{\lambda_E}}$$

- Foglio excel



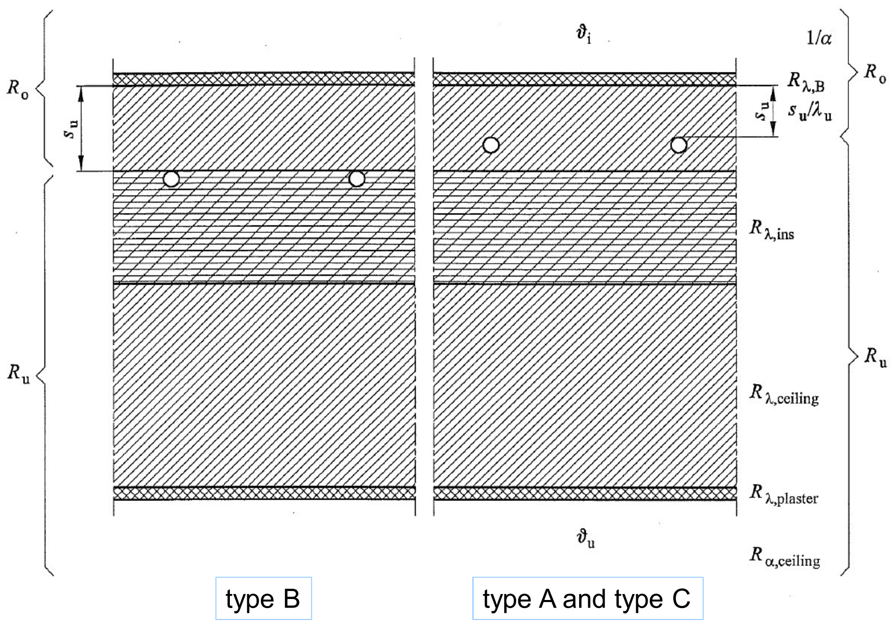
Downward Heat Losses

- The downward specific heat loss towards rooms under the radiant heating system is calculated with the following equation:

$$q_U = \frac{1}{R_U}(R_0 * q + \theta_i - \theta_U)$$

where:

q_U	downward specific heat loss
q	specific thermal output of the floor heating system
R_U	downwards partial heat transmission resistance of the floor structure
R_O	upwards partial heat transmission resistance of the floor structure
ϑ_i	standard indoor room temperature of the floor heated room
ϑ_U	indoor room temperature of a room under the floor heated room



- Upwards partial heat transmission resistance of the floor stucture

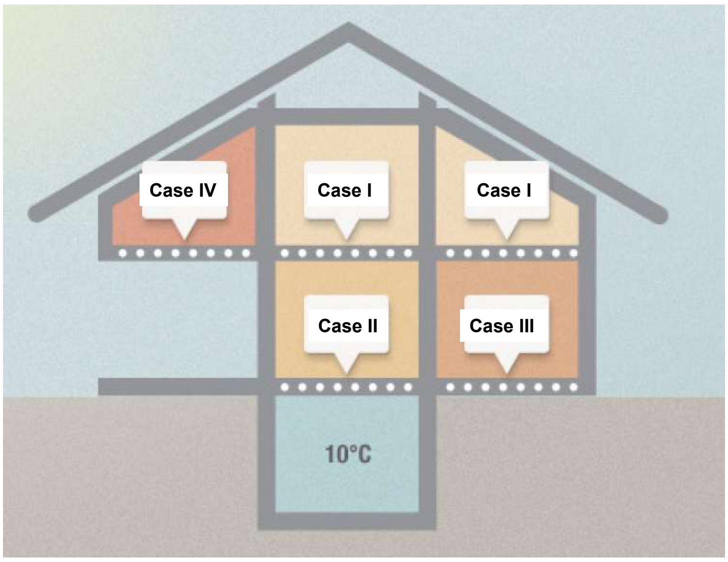
$$R_0 = \frac{1}{\alpha} + R_{\lambda,\mathrm{B}} + \frac{s_U}{\lambda_U}$$

$1/\alpha = 0.0926 \ \frac{m^2K}{W} \quad con \quad \alpha = 10.8$

- Downwards partial heat transmission resistance of the floor structure

$$R_U = R_{\lambda,ins} + R_{\lambda,ceiling} + R_{\lambda,plaster} + R_{\alpha,ceiling}$$

$1/\alpha = 0.17 \ \frac{m^2K}{W} \quad con \quad \alpha = 5.9$



Case	Boundary condition below	Th. Resist. [W/(m² K)]	Minimum required thickness [mm]		
			k = 0.025 W/(m K)	k = 0.035 W/(m K)	k = 0.040 W/(m K)
I	Heated room	0,75	19	27	29
II / III	Unheated or ground	1,25	31	44	50
IV	Outdoor temp. >0°C	1,25	31	44	50
IV	-5°C < outdoor temp. < 0°C	1,50	38	53	60
IV	-15°C < outdoor temp. < -5°C	2,00	50	70	80

- The total heat flow of the system is the sum of the thermal output of the system (q) and the downwards heat loss (q_U).

- The design water flow rate can be calculated with the following equation:

$$m_H = \frac{A_F \cdot q}{\sigma \cdot c_W} \cdot \left(1 + \frac{R_o}{R_u} + \frac{\vartheta_i - \vartheta_u}{q \cdot R_u}\right)$$