RADIANT SYSTEMS

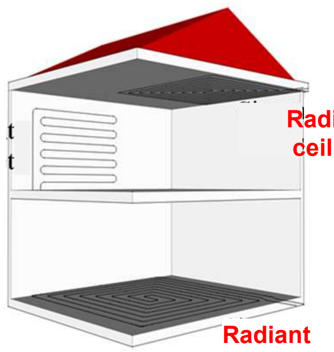
Radiant systems

1. Type of radiant systems
2. Heat transfer phenomena
3. Sizing radiant systems

1. Types of radiant systems

Types of radiant systems

Screed: massetto
Gypsum board: cartongesso



Radiant wall → Prefabricated elements and Built up on-site

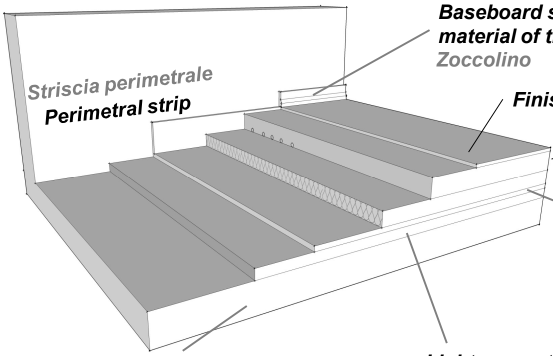
Radiant ceiling → Metal panels, Gypsum board, TABS

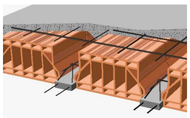
Radiant floor → Traditional (high inertia) and Low thickness (low inertia)

Dry

With traditional and fluid screed

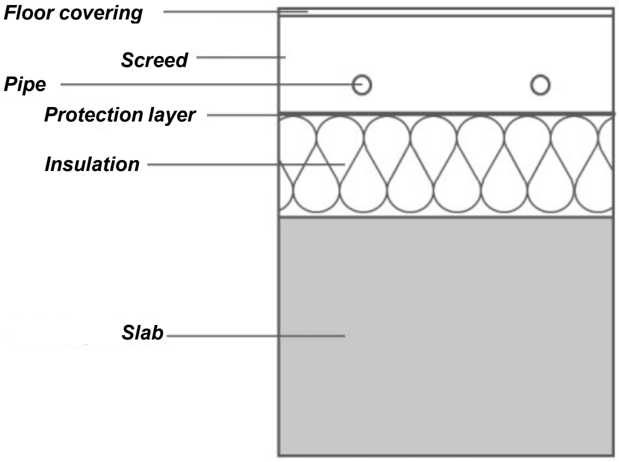
Components of a radiant floor





Solaio strutturale portante

Classic radiant floor (high inertia)

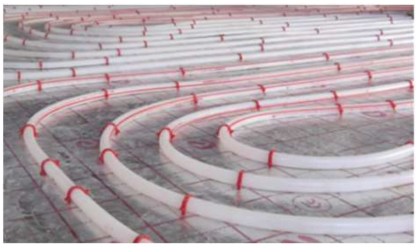


Standard EN 1264: Type A

Classic radiant systems

Use: residential buildings and offices

Fixing systems for the pipes with clips



Velcro tape

Wire mesh & clips

Clip su rete metallica

Rusticated insulating panel

Isolamento con lastra bugnata

Industrial floor radiant system

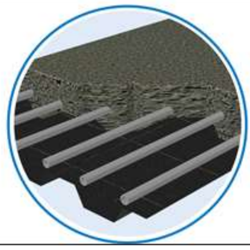
Pipes fixed on welded mesh

External diameter of the pipe: 25 mm

Pipes fixed on welded mesh and pylons armature

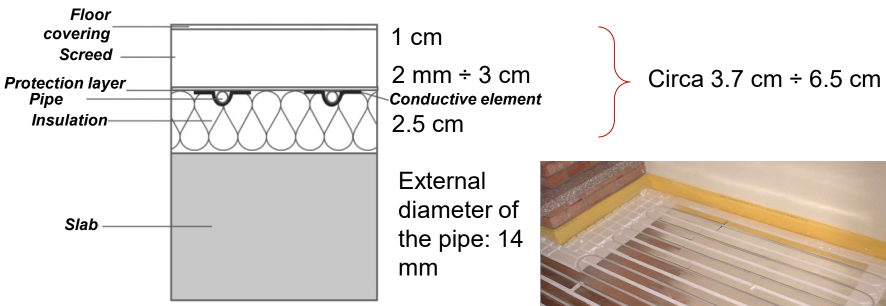
rete elettrosaldata e traliccio di armatura

TABS: Thermo-Active Building systems

TABS	Application	
System with prefabricated welded mesh	Office buildings and industrial buildings	
Light filling materials in structural slabs	Office Buildings	
Corrugated sheet	Office Buildings	

Low thinckess radiant floor

Use: residential buildings and tertiary buildings



External diameter of the pipe: 14 mm

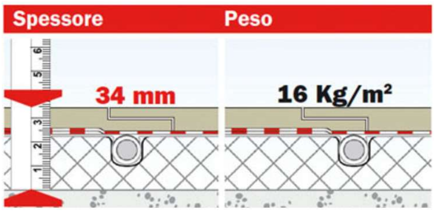
Pipes embedded in the insulation

Dry systems – Thickness: circa 25 mm

Steel sheet – Thickness: 1 mm

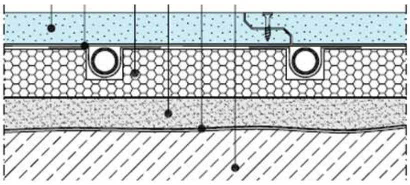
Self-levelling screed (with addivites - 30 mm)

Low thickness Radiant systems 1/3



Calciosilicato

Calciumsilicate sheet
thickness: 9 mm
Therma conductivity: 0.35 W/(m K)
Usual size of the boards: 1.2 m x 1.2 m



Fibrogesso

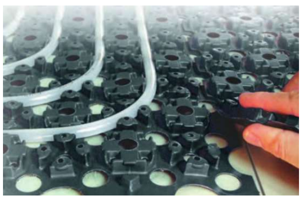
Plaster fibre sheet
thickness: da 18 a 25 mm
Thermal conductivity : 0.28–0.32 W/(m K)
Limit temperature: 45°C

Lastra in acciaio

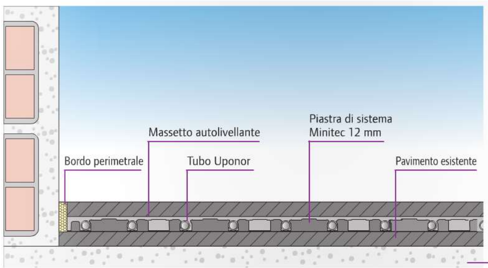
Steel sheet
Limited thickness (2 mm)
High conductivity
Quick installation
Relevant costs

Low thickness Radiant systems 2/3

Pipes inserted in prefabricated panels

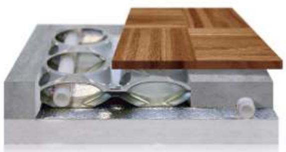


Pipes diameter:
9.9 x 1 mm



1 cm
1.5 cm
2.5 cm

Pipes inserted in prefabricated metal structures



1.5 cm

Low thickness Radiant systems 3/3

Tubazioni inserite in un supporto fresato

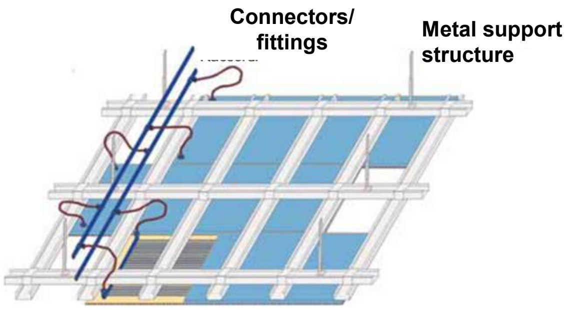
Pipes inserted in milled in support layer

s = 0 mm

Modular systems for raised floors

Sistemi radianti modulari per pavimenti flottanti

Ceiling radiant systems 1/2

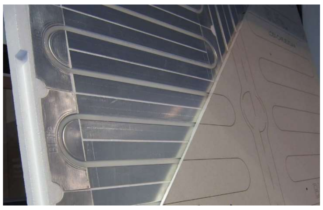


Ceiling radiant systems 2/2

Gipsum board, insulation and pipes. Prefabricated solution

Pipes embedded in the milled gipsum board

Pipes embedded in the insulation with conductive metal sheets and planar gypsum boards

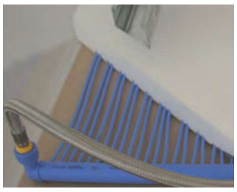


Residential and office buildings

Metal elements (usually hollowed metal sheets) with plastic and metal pipes

Office buildings

Capillary pipes in radiant ceiling systems



Radiant ceiling Vs. floor

Smaller pipe diameters in the ceiling than in radiant floors (6 ÷ 10 mm external diameter).

In ceiling shorter water circuits than floor radiant systems.

Lower water velocity in ceiling radiant systems than in floor radiant systems.

Temperature difference:

	Heating	Cooling
Floor	3÷7	2÷3
Ceiling	2÷3	3÷4

In both systems the perimetral strip has to be installed.

As an alternative the radiant ceiling has to be finished above the wall.

The ceiling can have sound-absorbing characteristics: acoustic comfort possibility combined with the hollow structure.

With radiant floor the screed has to be decoupled acoustically for tapping noise.

Perimetral strip

The perimetral strip allows the expansion of the support layer embedding the pipes




The standard EN 1264 declares that the minmum thickness of the perimetral strip has to allow at least 5 mm expansion.
Usually the thicnkess varies from 5 to 8 mm.

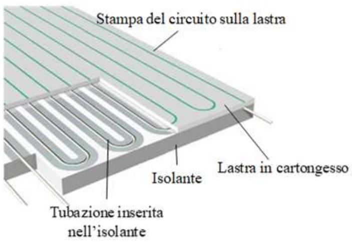

Important: surround pillars and stairs, if any

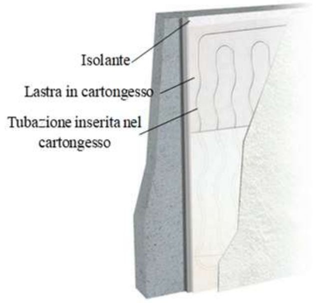
Walls radiant systems 1/2

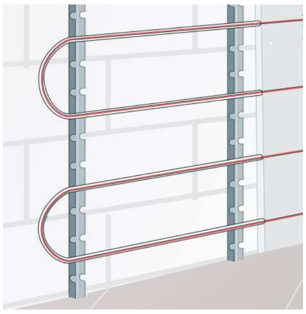


Walls radiant systems 2/2

Pipes embedded in prefabricated panels (similar to radiant floors)



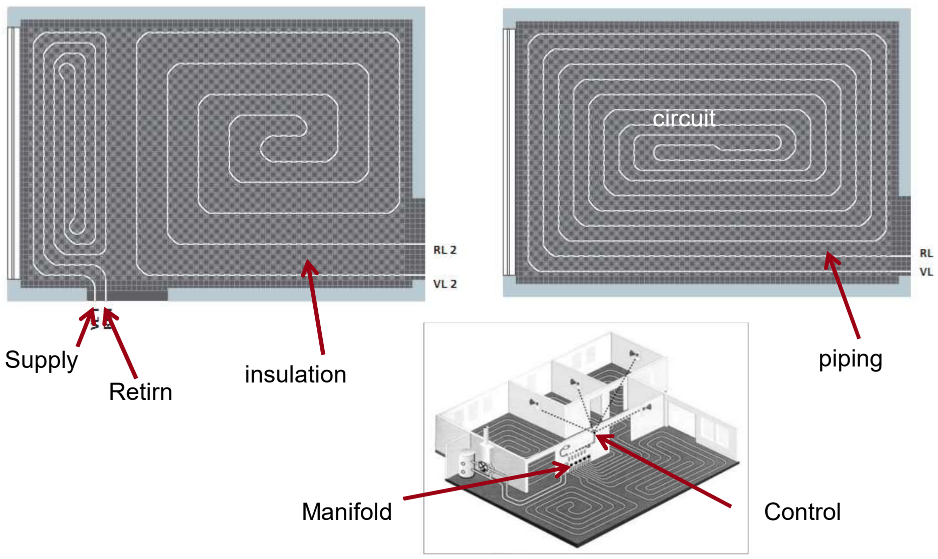




Pipes coupled to fixing elements on the wall

Walls radiant systems are not frequent (limits in the furniture, pictures, ecc.).
Interesting as integrated systems in the retrofit of buildings when internal insulation is foreseen.

Components of a radiant system



Manifold

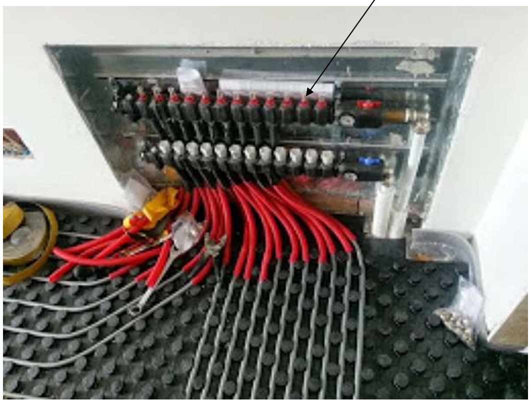
Automatic venting: it is installed at the highest point of the hydronic circuit

Flussimetro

Flowmeter

Metal

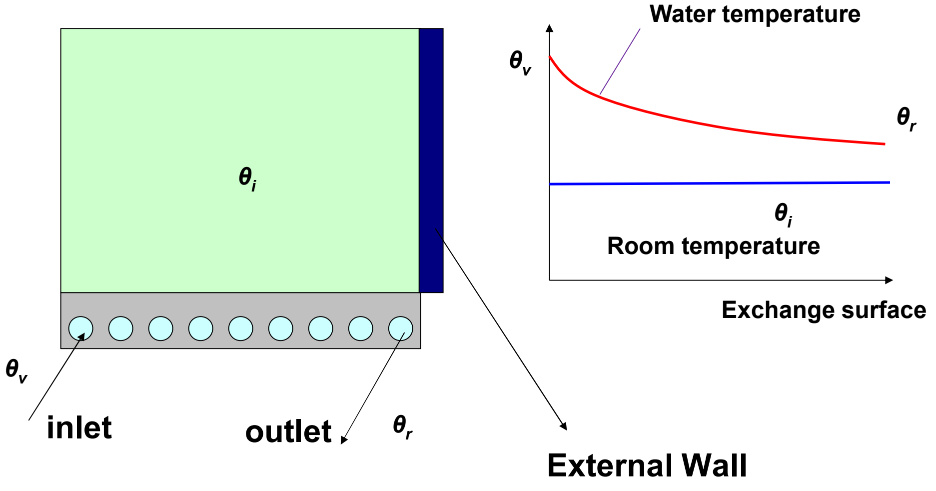
Plastic

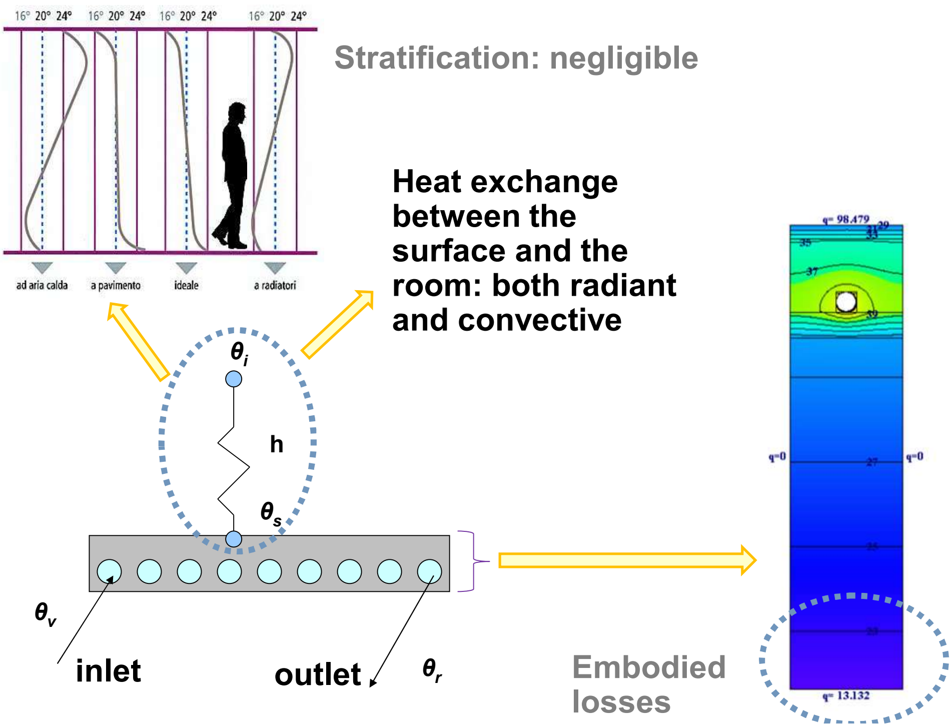


Usual screed

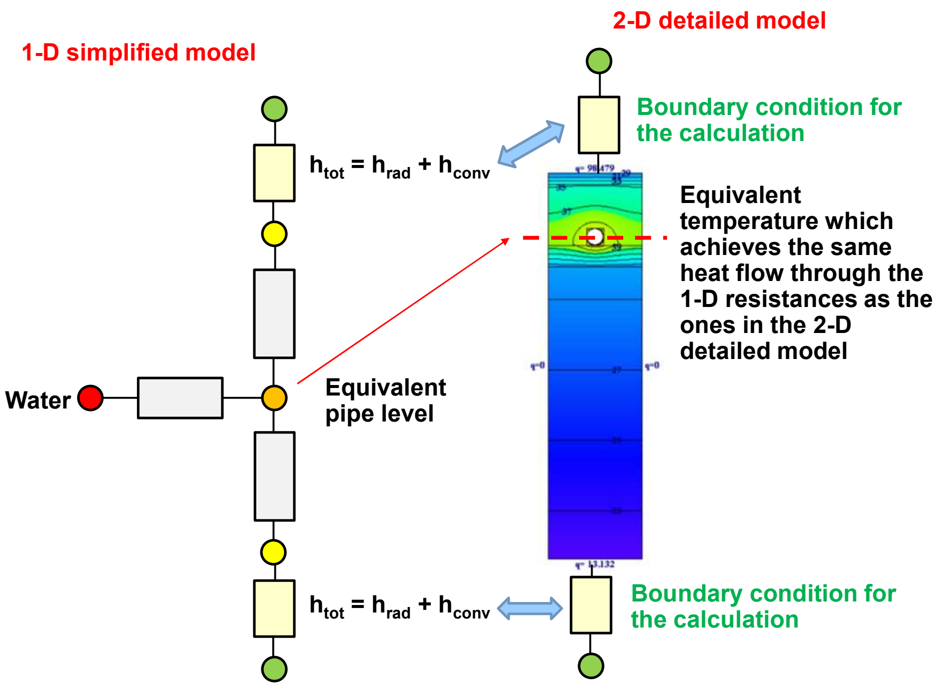
Self-levelling screed

2. Heat transfer phenomena



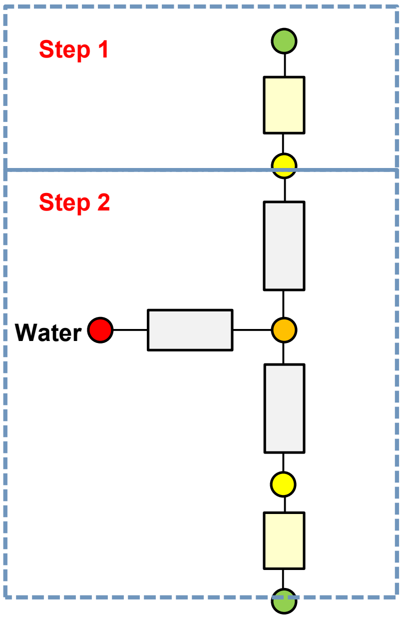


16° 20° 24°
ad aria calda
a pavimento
ideale
a radiatori
Stratification: negligible
Heat exchange between the surface and the room: both radiant and convective
θi
h
θs
θv
inlet
outlet
θr
Embodied losses



1-D simplified model
2-D detailed model
htot = hrad + hconv
Boundary condition for the calculation
Equivalent temperature which achieves the same heat flow through the 1-D resistances as the ones in the 2-D detailed model
Water
Equivalent pipe level
htot = hrad + hconv
Boundary condition for the calculation

Design steps for sizing the radiant system



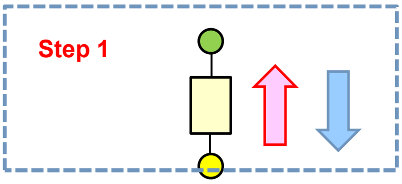
Useful heat exchange between the surface and the room = f (indoor temperature, peak load, surface orientation, local discomfort parameters)

Heat exchange between the water and the structure = f (surface orientation, pipe diameter, layer, surface finishing, pipes spacing)

Step 1: heat exchange between the surface and the room

Overall surface heat exchange coefficients

System Type		RADIANT [W(m^2 K)]	CONVECTIVE [W(m^2 K)]	TOTAL [W(m^2 K)]
Floor	Heating	5.5	5.5	11
	Cooling	5.5	1.5	7
Wall	Heating	5.5	2.5	8
	Cooling	5.5	2.5	8
Ceiling	Heating	5.5	0.5	6
	Cooling	5.5	5.5	11



Specific Peak Load q:

q = Peak power / active area [W/m²]

$q = h_{tot} \times | t_{surf} - t_i |$ [W/m²]

To compare against the maximum/minimum allowable temperature for local discomfort

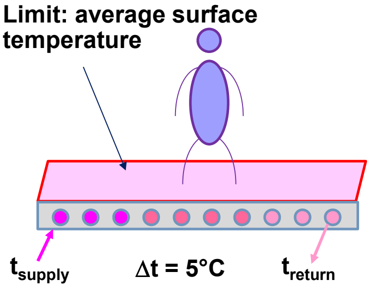
Maximum flow rate: flow rate with the maximum (in heating) and minimum (in cooling) allowable temperature for the surface

Heating: $q_{max} = h_{tot} \times | t_{surf,\ max} - t_i |$ [W/m²]

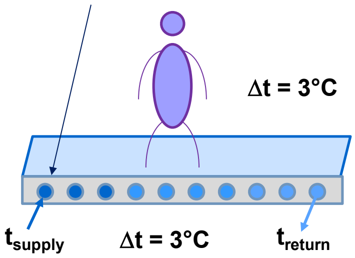
Cooling: $q_{max} = h_{tot} \times | t_{surf,\ min} - t_i |$ [W/m²]

Floor surface temperature limits:

Limit: average surface temperature



Limit: minimum surface temperature on the top of the room water inlet

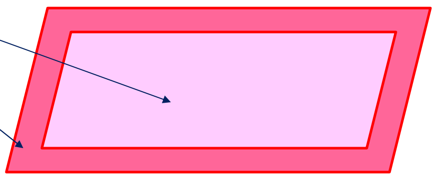


Minimum local surface temperature: on the top of the room water inlet (19°C). The average temperature of the floor will be about 19 +1.5 = 20.5°C

Maximum surface temperature: average surface temperature.

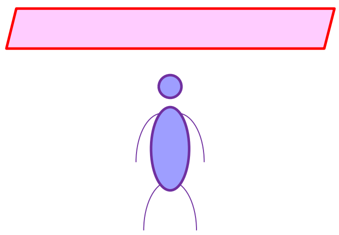
29°C in the occupied area

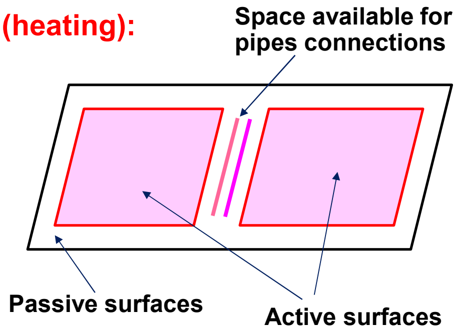
35°C in the peripheral area



Ceiling surface temperature limit (heating):

Limit: average surface temperature





Active area: ~70% of overall area

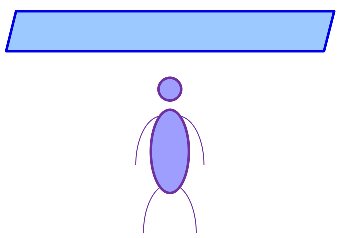
Maximum surface temperature of active area: radiant vertical asymmetry 5°C

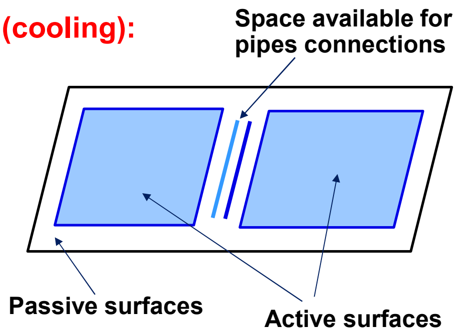
Usually it is a difficult parameter to calculate in design phase. Hence approximately it is estimated as a maximum surface temperature. This parameter is under discussion and recently the temperatures have been risen compared to the past (when a suggested temperature of 30-32°C was provided). The following temperature can be used:

t_{max} =35°C in the active area

Ceiling surface temperature limit (cooling):

Limit: average surface temperature





Active area: ~70% of overall area

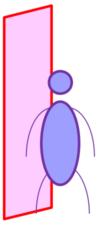
Minimum surface temperature of active area: not a question of radiant vertical asymmetry.

The minimum temperature depends on the dew point temperature. In general the following temperature can be assumed for the active area:

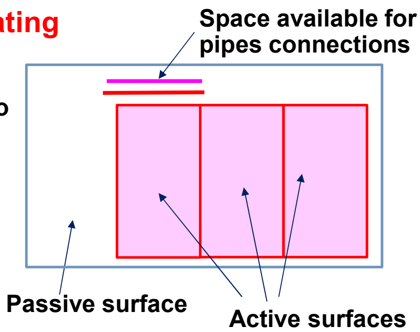
t_{min} =18°C in the active area

Wall surface temperature limits (heating and cooling):

Limit: active surface temperature (difficult to know the passive area and not very useful)



Maximum in the range 35 – 50 °C. The maximum may depend on the application of the wall heating system. If it is used in areas where the occupants may easily get contact with the surface or not. If it is used in buildings for more sensitive persons like children or elderly, the risk for burns and pain is a skin temperature of 42-45 °C.



Active area: ~70% of overall area (even less)

The losses to the backside must be considered.

t_{max} =40°C in the active area

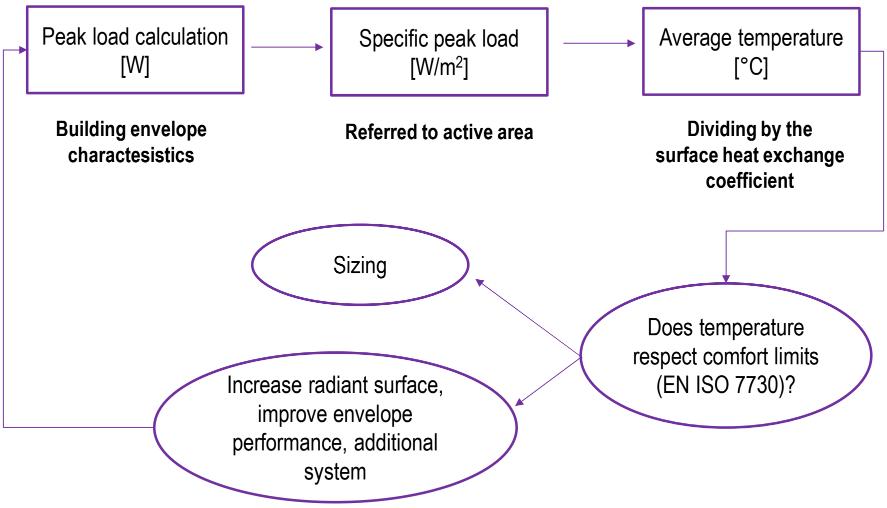
The minimum temperature depends on the dew point temperature. In general the following temperature can be assumed for the active area:

t_{min} =18°C in the active area

Maximum specific power of a radiant system

			t_{min}/t_{max} [°C]	h_{tot} [W/(m² K)]	t_i [°C]	q_{max} [W/m²]
FLOOR	Occupied	Heating	29	11	20	100
		Cooling	20	7	26	40
	Peripheral	Heating	35	11	20	165
		Cooling	19	7	26	50
CEILING	Active area	Heating	35	6	20	90
		Cooling	18	11	26	88
	Overal area	Heating	30.5	6	20	63
		Cooling	20.5	11	26	60
WALL	Active area	Heating	40	8	20	160
		Cooling	19	8	26	55

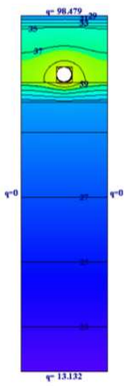
Step 1: Resume



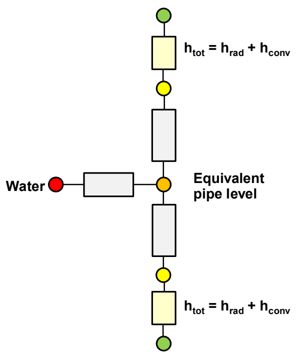
Step 2: Sizing

There are 4 methods for sizing a radiant system:

Method 1: Detailed 2-D calculation method



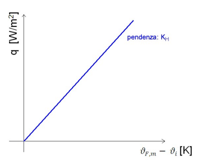
Method 2: Simplified 1-D calculation method

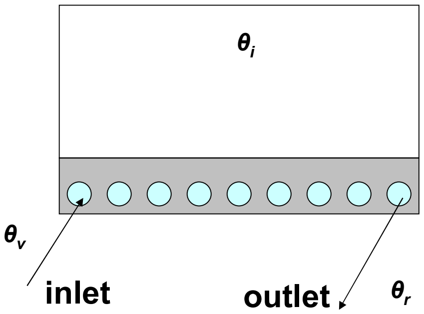


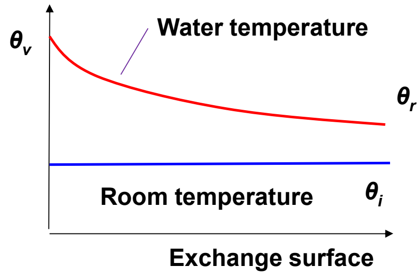
Method 3: Simplified Black-box calculation method

Geometry
Thermal properties of materials
Etc.

Method 4: Heat transfer through certified tested values

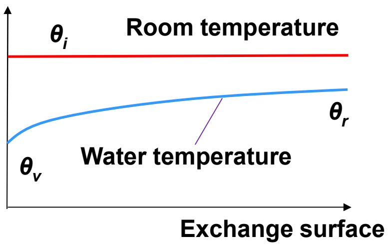






$$q_H = K_H \Delta\theta_H$$

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



$$q_C = K_C \Delta\theta_C$$

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

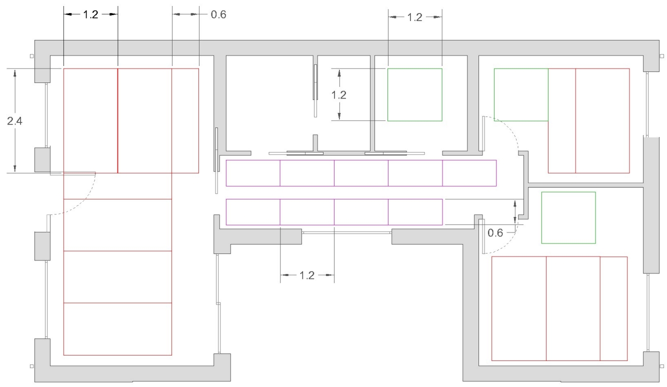
Sizing radiant walls and ceilings:

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

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

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

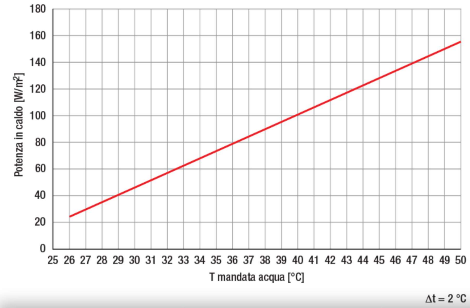
$$q_C = K_C \Delta\theta_C \longrightarrow q_C = \dot{m} c_p (\theta_{v,C} - \theta_{r,C})$$



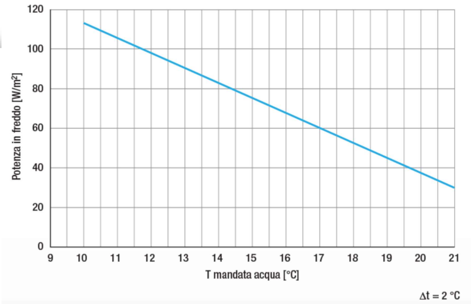
In this case the systems are prefabricated. The producer will provide the curves for K_H, K_C and the Δp as a function of the flow rates of the system

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.



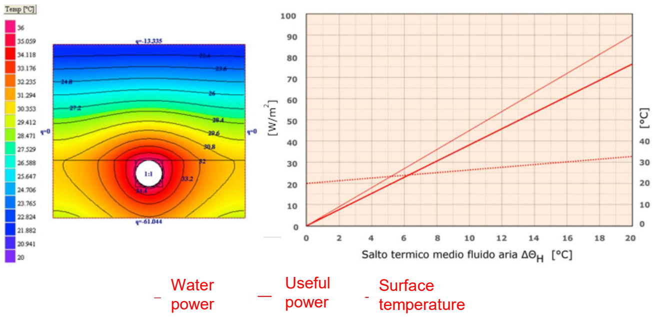
EN 14037-5 (laboratory test for radiant ceiling in heating)

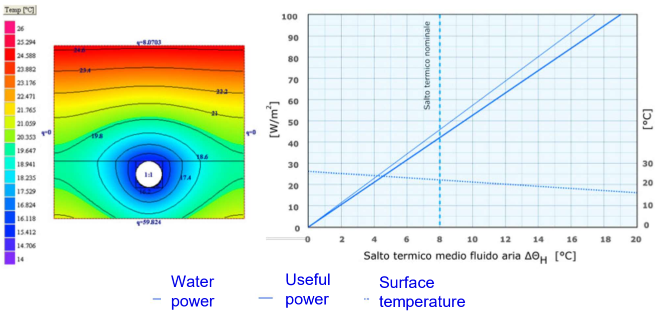


EN 14240 (laboratory test for radiant ceiling in cooling)

Source: Eurotherm

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





Source: Rossato

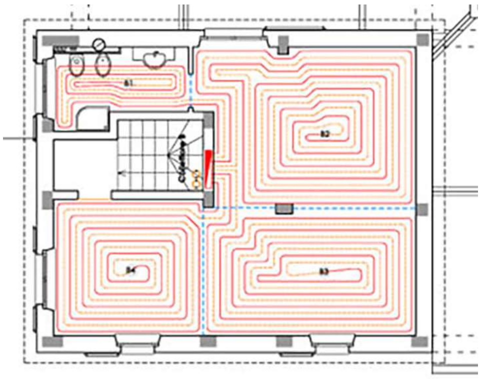
Sizing radiant floors:

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/$\Delta\theta_{water}$:

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

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



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

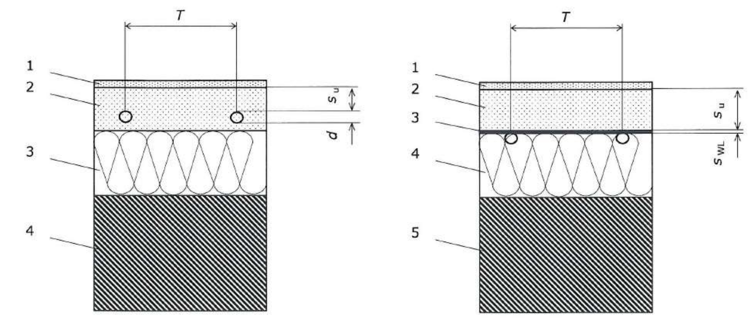
•**Type D** include plane section systems (extruded plastic / group of capillary grids)

•**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

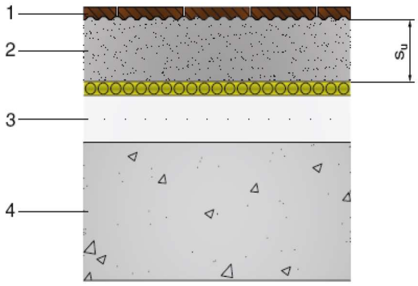
Figure 2 a) Systems of type A and C

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

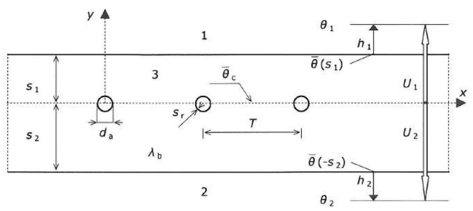
– Part 1 – definition of radiant systems



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

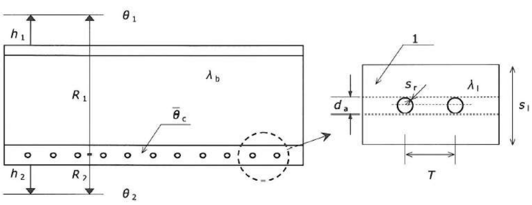
Plane section systems, type D covered by the method in EN 1264

– 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

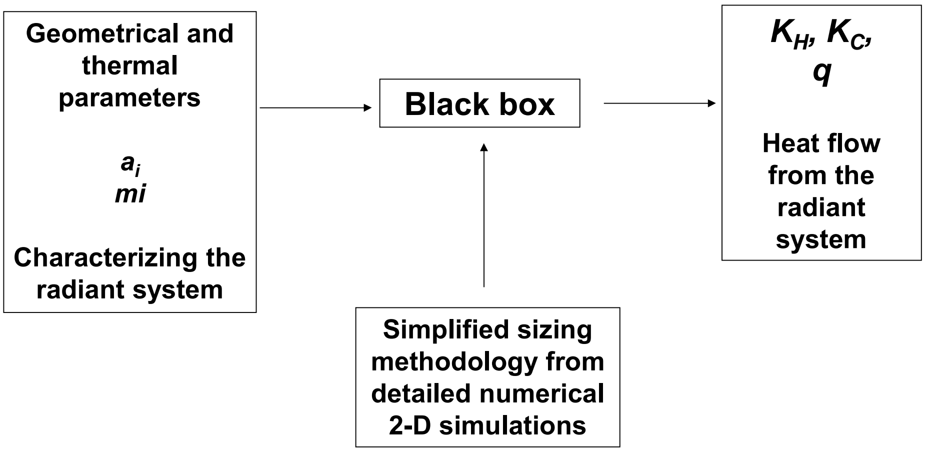
For each type of radiant system (A,B,C,D,F,G) there is a method for the calculation:

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)	$T \geq 0{,}050m$ $S_u \geq 0{,}01m$ $0{,}008\ m \leq d \leq 0{,}03\ m$ $S_u / \lambda_e \geq 0{,}01$
In insulation, conductive devices, one side loss less than or equal to 10 % of total	B	2b)	$0{,}05 \leq T \leq 0{,}45m$ $0{,}014\ m < d < 0{,}022\ m$ $0{,}01 \leq S_u / \lambda_e \leq 0{,}18$
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:



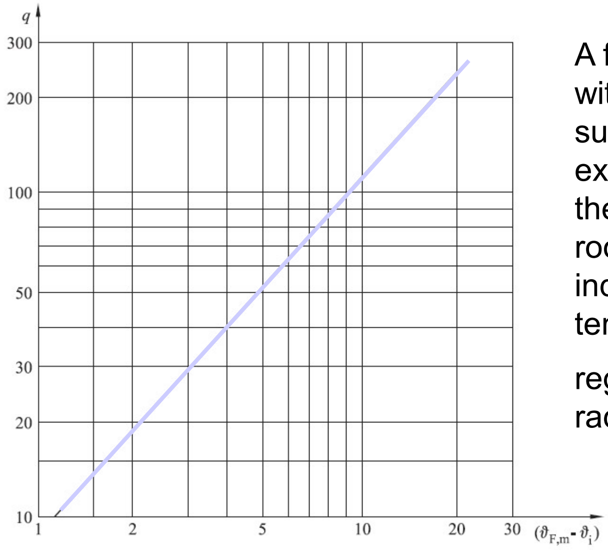
Thermal boundary conditions

- 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: $\boldsymbol{m_H/d_i > 4\,000}$ **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.

General Approach

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

B type (applies to λ_R, a_K)

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

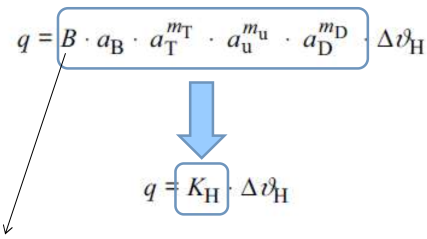
The specific thermal output is calculated with:

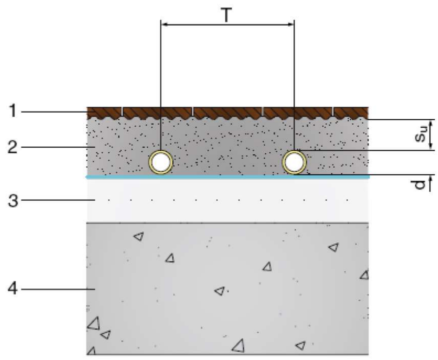
$$q = f[(\Delta\theta_H)^n] \quad \Rightarrow \quad q = B * \prod_i (a_i^{m_i}) * \Delta\theta_H$$

- B system-dependent coefficient [W/(m²K)];
- $\prod_i (a_i^{m_i})$ 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.





B → B_0 = 6.7 W/(m²K) 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

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

α = 10,8 W/(m² · 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 m² · K/W;

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

- a_T →is the spacing factor

$R_{\lambda,B}$ m² · 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

$R_{\lambda,B}$ m² · 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

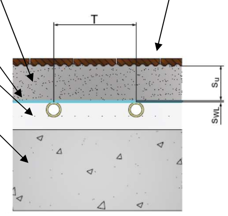
$R_{\lambda,B}$ m² · K/W	0	0,05	0,10	0,15
T (m)	a_D			
0,05	1,013	1,013	1,012	1,011
0,075	1,021	1,019	1,016	1,014
0,1	1,029	1,025	1,022	1,018
0,15	1,04	1,034	1,029	1,024
0,2	1,046	1,04	1,035	1,03
0,225	1,049	1,043	1,038	1,033
0,3	1,053	1,049	1,044	1,039
0,375	1,056	1,051	1,046	1,042

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

type B

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

$a_K = f(T)$ — 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:

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

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 $a_{WL} = f(K_{WL}, T, D)$

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

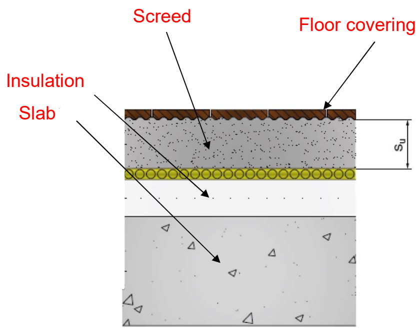
$s_{WL} \cdot \lambda_{WL} = f(T)$

a_B is the floor covering factor

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

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

type D



$$q = B \cdot a_{\mathrm{B}} \cdot a_{\mathrm{T}}^{m_{\mathrm{T}}} \cdot a_{\mathrm{u}} \cdot \Delta\vartheta_{\mathrm{H}}$$

where

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

$a_{\mathrm{T}}^{m_{\mathrm{T}}}$ $= 1{,}06$;

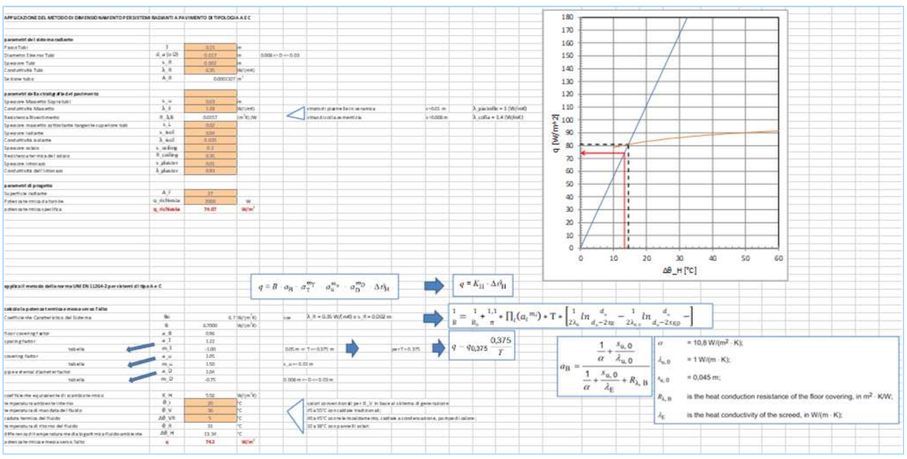
a_{u} is the covering factor in accordance with Equation (12);

a_{B} is the floor covering factor:

$$a_{\mathrm{B}} = \frac{1}{1 + B \cdot a_{\mathrm{u}} \cdot a_{\mathrm{T}}^{m_{\mathrm{T}}} \cdot R_{\lambda,\mathrm{B}}}$$

$$a_{\mathrm{u}} = \frac{\dfrac{1}{\alpha} + \dfrac{s_{\mathrm{u},0}}{\lambda_{\mathrm{u},0}}}{\dfrac{1}{\alpha} + \dfrac{s_{\mathrm{u}}}{\lambda_{\mathrm{E}}}}$$

Excel tool



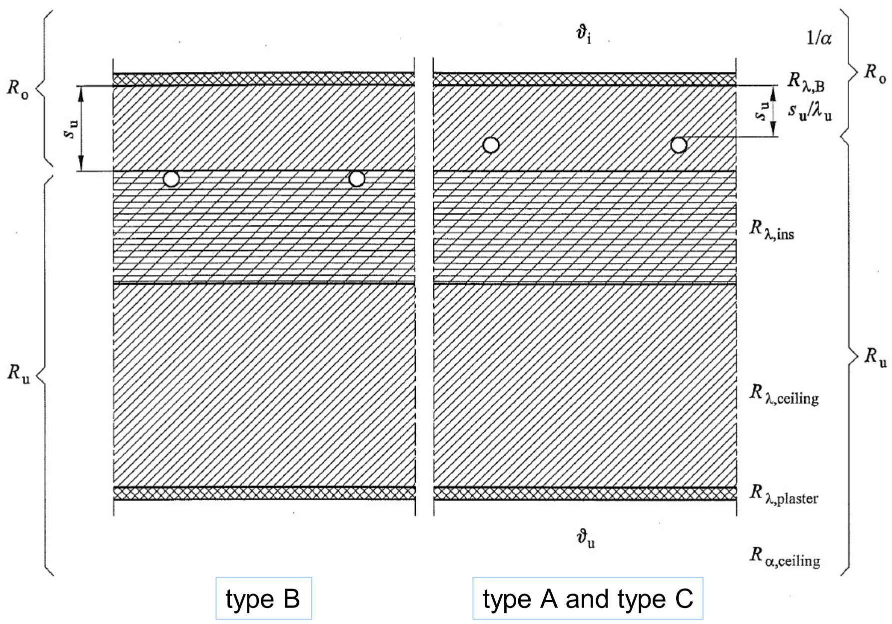
Downward Heat Losses

- 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

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

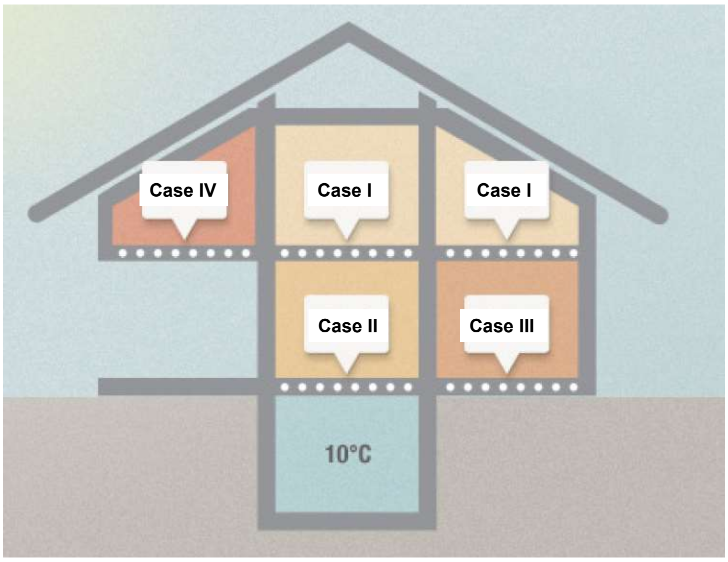
$1/\alpha = 0.0926 \ \frac{m^2K}{W}$ $\quad con \quad \alpha = 10.8$

- Downwards partial heat transmission resistance of the floor structure

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

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

Thermal Insulation



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

Design of the Water Flow Rate

- 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:

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