The calculus and simulation of underfloor heating systems

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Abstract: Calculus methods for heat load and energy consumption in buildings available in Romania were developed before large-scale development of advanced computer equipment and computer programs or advanced simulation techniques, which is why we have base computational models of simple conduction in steady state. Therefore, based on these methodologies we cannot make detailed analyzes regarding heat load and energy consumption in built environment. The main objective of our work is to compare the established Romanian methodology of heat load calculation with that of the MC4 SUITE software and to validated by the means of a 3D computer simulation.

Key-Words: heating system, underfloor heating, tempered concrete, heat load calculation, MC4 SUITE software, 3D computer simulation.

1 Introduction

Generally, the designing of the heating systems relies on the calculation of the heat demand of each heated enclosure.

In Romania the under floor heating systems are designed accordingly to STAS 1907/97 that contains specific provisions for the buildings heated with low temperature radiant systems.

In the recent years designers started to use the European methodology of calculation DIN EN 1264.

The purpose of this work is to compare the results obtained with the above described methodologies with those obtained using a simulation software and with the actual measured values.

2 Problem Formulation

Regardless of the type of heating system, the sizing is based on the heat of heated space determined in accordance with the requirements of SR 1907/1 and 2 from 1997. The standard contains specific provisions for rooms fitted with low temperature radiation underfloor heating.

Floor heating is part of the still heating surfaces, with radiators, convectors, and so on. It is a result of adaptation of a building element to a heating element, namely floor. Basically, a network of pipelines (coil) through which the heat is embedded:

- either directly to the floor slab, in which case the system is known as "tempered concrete";
- either in a layer of screed poured concrete slab of the floor, in which the system is known as underfloor heating or “warm floor”;
- steps that must be taken in order to dimension of such a system are:
  - type of coil is adopted to satisfy the application requirements largely concerned;
  - surface temperatures on the floor and in the adjoining rooms;
  - calculate temperature differences and heat resistance of the component layers of the slab;
  - calculate the flow of heat from the floor, water flow required and the pipes diameter and the distance between them.

For our laboratory the heat demand calculation was done according to SR 1907/1 and 2, the resulting Q = 2952.29 W, considered the thermotechnic characteristics of building elements and the physical characteristics of the room.

To determine the optimal characteristics of thermal insulation system and under floor heating installations we have done two sets of calculations, a simulation by MC4 SUITE HVAC CAD engineering calculations program developed by Mc4Software Italy and a set of calculations using a routine developed according to the methodology of calculation DIN EN 1264-2:2009 "Water based surface embedded heating and cooling systems - Part 2: Floor heating: Prove methods for the determination of the thermal output using

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calculation and test methods; German version EN 1264-2:2008 "

For the studied case, namely Laboratory for the Study of heating / cooling radiation were designed and built four individual heating zones with radiant floor heating which is powered by four circuits with the following characteristics:

- Zone 1 (1006) is provided with an pre grooved and foiled extruded polystyrene insulation with a thickness of 0.05 m, on which the heating coils are laid. In this area, approximately 9.3 m^2 was laid a double helical coil type circuit made with polyethylene pipes Ø 17 mm, 100 mm pitch and length of 81 m. Over the heating system was poured a concrete screed with a thickness of 0.05 m with no additives and with a cement content of 200 kg/m^3. The flooring of this area has been done with a triple-layered hardwood, 14 mm thick, bonded with adhesive on the leveling screed.

- Zone 2 (1007) is provided with an pre grooved and foiled extruded polystyrene insulation with a thickness of 0.05 m, on which the heating coils are laid. In this area, approximately 9.1 m^2 was laid a double helical coil type circuit made with polyethylene pipes Ø 17 mm, 100 mm pitch and length of 96 m. Over the heating system was poured a concrete screed with a thickness of 0.05 m with super plasticizer additive and with a cement content of 300 kg/m^3. The flooring of this area has been done with laminate flooring, 10 mm thick, laid on a EPS foiled separation layer.

- Zone 3 (1008) is provided with an pre grooved and foiled extruded polystyrene insulation with a thickness of 0.05 m, on which the heating coils are laid. In this area, approximately 14.7 m^2 was laid a double helical coil type circuit made with polyethylene pipes Ø 17 mm, 150 mm pitch and length of 93 m. Over the heating system was poured a concrete screed with a thickness of 0.05 m with super plasticizer additive and with a cement content of 300 kg/m^3. The flooring of this area has been done with ceramic floor tiles, 8 mm thick, bonded on the screed with cement adhesive.

- Zone 4 (1009) is provided with an pre grooved and foiled extruded polystyrene insulation with a thickness of 0.05 m, on which the heating coils are laid. In this area, approximately 15.2 m^2 was laid a double helical coil type circuit made with polyethylene pipes Ø 17 mm, 150 mm pitch and length of 93 m. Over the heating system was poured a concrete screed with a thickness of 0.05 m with no additives and with a cement content of 200 kg/m^3. The flooring of this area has been done with PVC linoleum, bonded with adhesive on the leveling screed.

The design of the underfloor heating system is shown in figure 1.

Circuit	Lungime[m] Circuit	Lungime[m] Total	Debit [l/h]	Pasul [mm]	Reglajul vanei de echilibrare
1006- 1	81.0	82.0	47.9	100 : 0	0,75
1007- 1	90.0	99.0	87.2	100 : 0	1,25
1008- 1	92.0	95.0	128.0	150 : 0	2
1009- 1	97.0	101.0	180.5	150 : 0	4,25

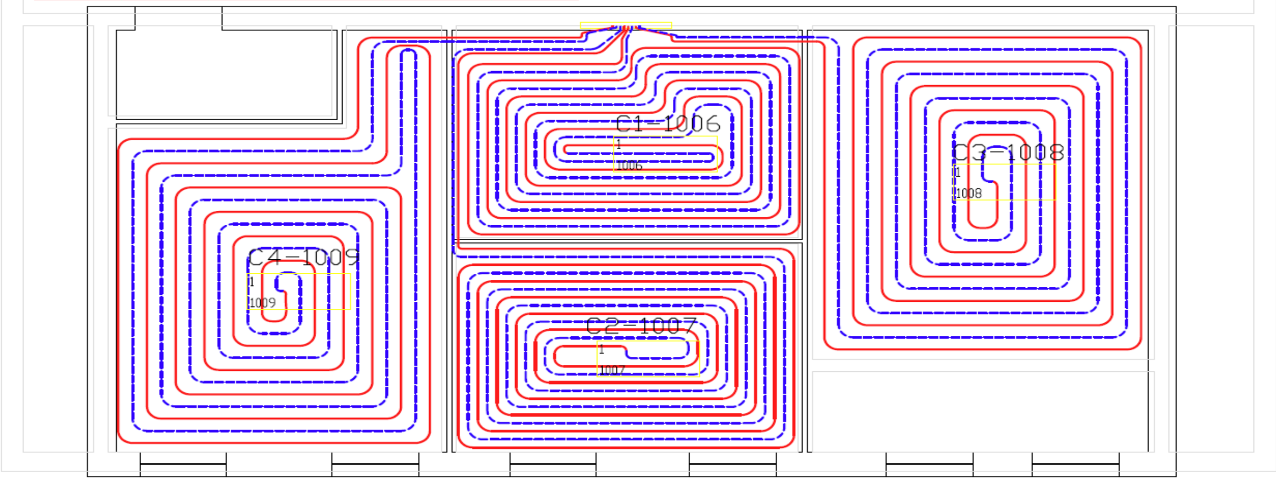

Fig. 1 Underfloor heating design

In the laboratory it was designed and built a temperate concrete slab with a thickness of 25 cm and dimensions W = 2 m and L = 3 m, which was placed on a steel structure. Tempering the concrete core was made by inserting a heating / cooling coil made of PE-Xa RAUTHERM Ø 20 x 2.0 mm with the pitch of 15 cm in the middle of the slab. In order to study its performance has been provided a total of eighteen surface temperature sensors, applied 9 to the lower surface and nine to the upper surface.

The studying of the performance of heating through the walls is done on four independent sections, two PE-Xa pipe Ø 10.1 × 1.1 mm wet construction, and two with PE-Xa pipe Ø 10.1 × 1.1 mm in dry wall construction. Each section was provided with surface temperature sensors, one on the interior surface of the lab and one on the wall surface in adjacent rooms.

On the ceiling we have built two heating systems, as follows:

- two dry wall gypsum ceiling tiles, impregnated and fiber reinforced core according to DIN 18180 / DIN EN, pre-equipped with RAUTHERM S 10.1 x 1.1 mm pipes, with the pitch of 45 mm;
- two heating plastic modules installed in the suspended ceiling, with dimensions of 550 × 550 mm fitted with heat resistant rear panels produced by RBM Italy.

All heating modules are provided with contact sensors for temperature measurements.

Hot water supply for heating is assured from a source external to the laboratory, a ground to water heat pump.

The heat supplied by the heat pump for heating will adjust parameters within the following ranges: td = 25 ÷ 45 °C; ti = 20 ÷ 35 °C.

The calculus of heating systems with radiant flooring is made basically following the algorithm:

a) Determine the heat flow unit that should be provided in order to cover the whole quantity of heat needed for the room:

$$q_{nec} = \frac{Q_{nec}}{S_{pl}} \quad (1)$$

where:

Q_{nec} - heat demand calculation according to SR 1907/1-97 [W];

S_{pl} - the surface of the floor that is being heated by means of hydronic systems [m^2].

b) Determine the temperature that should have the floor surface in order to provide uniform heat flow determined above:

$$\theta_{pl} = \theta_i + \frac{q_{pl}}{\alpha_{pl}} \quad (2)$$

where:

θ_i - indoor temperature calculation, according to SR 1907/1-97 [° C];

α_{pl} - surface coefficient of heat exchange from the floor.

Maximum floor surface temperature, according to health and hygiene, is: $\theta_{pd}^{max} = 29[°C]$

Namely, we have two situations:

- θ_{pl} (determined by the relation above) $< \theta_{pl}^{max} = 29[°C]$, which means that the floor can provide the heat throughout the room;
- θ_{pl} (determined by the relation above) $< \theta_{pl}^{max} = 29[°C]$, which means that the floor can not provide all the heat of the room.

In this case must be studied the possibilities of adding other heating systems for the part of the heat load that cannot provide floor.

To do this, firs take the maximum allowed floor temperature $\theta pd = \theta pd$ max = 29 [°C]. Than, accordingly to the temperature difference, with a chart will determine the heat flow coefficient from the floor to the inside air. For our example $\alpha_i = 8{,}92\ W/m$ and calculate the maximum heat flow unit that floor can provide in this case:

$$q_{pl} = \alpha_i (29 - \theta_i) \quad (3)$$

The difference is the calculus of heat load that is supposed to be provided from auxiliary sources:

$$q_{aux} = q_{nec} - q_{pl} \quad (4)$$

a) Determine global heat transfer coefficients of the flooring, ceiling, and floor:

$$k_{tv} = \frac{1}{\frac{1}{\alpha_{tv}} + \sum \frac{d_{tv}}{\lambda_{tv}}} \quad (5)$$

The sum of the reports d/λ in the above equation is the appropriate layers beneath the coil system that is embedded inside the heating system (excluding the screed layer which embeds the coil with thickness equal to the diameter).

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$$k_{pl} = k_{tv} + k_{po} \qquad (6)$$

b) Characteristic environment temperature is established for the under floor heating and the average temperature of the adjacent floor spaces.

There are two cases:

1. if the room is located above the basement, the temperature of the environment is being known;
2. if the room is placed on the ground, then the average ground temperature should be calculated using the following:
3.

$$\theta_s = \frac{\frac{S_c/S_{pl}}{R_c}\theta_e + \frac{S_{sl}/S_{pl}}{R_{sl}}\theta_{sl}}{\frac{S_c/S_{pl}}{R_c} + \frac{S_{sl}/S_{pl}}{R_{sl}}\theta_{sl}} \qquad (7)$$

where:

θ_e - outside air temperature (SR 1907/1-97);

θ_{sl} - groundwater temperature (SR 1907/1-97);

S_c - surface of the heated floor related to 1 m contour band besides exterior walls;

S_{sl} - heated floor area related to the central zone;

$$S_{pl} = S_c + S_{sl}$$

R_{sl} - Thermal resistance of the central area of the floor [m^2 K/W];

$$R_{sl} = R_{tv} + R_{sol}$$

R_{tv} - conductive thermal resistance of the heated floor lower layer (between the radiantsurface and soil) [m^2 K/W];

R_{sol} - conductive thermal resistance of soil layer between the slab and the groundwater [m^2 K/W];

R_c - corresponding thermal resistance of the band contour [m^2 K/W].

This is calculated by the formula:

$$R_c = \frac{\lambda_{sol}}{\pi} \cdot ln \frac{R_{tv} + \frac{\pi}{\lambda_{sol}}(1 - 0.5 \cdot \delta_p)}{R_{tv} + \frac{\pi}{\lambda_{sol}} \cdot 0.5 \cdot \delta_p} \qquad (8)$$

where:

λ_{sol} - thermal conductivity of the soil [W/m K];

δ_p - wall thickness [m].

The average temperature of the adjacent floor spaces is established, as the weighted average/mean temperature of the adjacent enviroments:

$$\theta_i^* = \frac{k_{po} \cdot \theta_i + k_{tv} \cdot \theta_s}{k_{po} + k_{tv}} \qquad (9)$$

3 Problem Solution

Between calculations done with MC4 software and those performed according to DIN EN 1264 are differences regarding the temperature difference in heating agent and heat flow, the calculation methodology in EN 1264 don't take into account the water temperature variation along the pipes and therefore the permanent changes of the temperature difference between the heating at the inlet of the pipe for heating and at the exit. The physical model can evaluate practical influence on the change of temperature difference thermal power generated by underfloor heating system.

From the heat load calculations conducted according to SR 1907/1 and 2 we have concluded that if the room it is to be heated with radiators, the transmission losses to ground will be 683.1 W, and if the room is to be heated by underfloor heating resulted that the heat loss to ground, by transmission will be 717.04 W.

In technical literature there is currently a unanimous reference about the changing of the operational temperature inside the heated enclosures using radiant heated floor, because of the average temperature increase radiation from the surface of the floor, knowing that the floor has the highest coefficient of mutual irradiation compared to occupants, especially in high rooms.

There is also an accurate assessment of the heat change following the implementation of these systems in heated spaces.

This change is a function of:

- reducing ventilation heat requirement, because the indoor air temperature is lower;
- increase heat loss by conduction through structural elements in contact with the ground.

Table 1 Calculated data by MC4 software versus the results obtained with the above methodology

Calculated Physical measures	MC4 SUITE HVAC CAD Results	Result obtained with the above methodology
Underfloor heating surface	S_{pl} = 54.8 m^2	S_{pl} = 54.8 m^2
Floor surface temperature	t_{po} = 25.6 °C	t_{po} = 25.9 °C
Global heat exchange coefficient for floor	-	k_{po}= 5.9 W/m^2K
Global heat exchange coefficient for ceiling	-	k_{tv} = 0.6 W/m^2K
Global heat exchange coefficient for entire system	-	k_{pl} = 6.5 W/m^2K
Conduction bound heat resistance for the elements between the radiant surface and soil	-	R_{tv} = 1.2 m^2K/W
Heat resistance of the central area of the floor	-	R_{sl} = 9.8 m^2K/W
Soffit concrete slab temperature	-	t_s = 19.6 °C
Heat flux generated downwards	-	q_{tv} = 13.1 W/m^2
Heat flux generated upwards	q_{pl} = 53.8 W/m^2	q_{po} = 67.1 W/m^2

4 Computational Parameters and Boundary Conditions

In order to validate the results obtained by the two methods previously described we have done a 3D computer simulation on the underfloor heating system, using the ANSYS 14 simulating software.

The model that we have created in order to simulate the heat transfer between the underfloor heating pipes upward to the room and downward to the ground takes into accounting a seven meter layer of soil, considering that it have a homogeneous structure and continuous heat transfer coefficient, regardless of the moisture content, a 15 cm of compacted gravel and a 10 cm concrete slab.

Was used in calculations the general basement configuration of a building whose geometry and boundary conditions used are shown in Fig. 1.

The used boundary conditions were [2]:

- the ground surface boundary conditions: a long wave emittance of 0.9, and a reflectance of 0.23.
- above the floor boundary conditions: constant air temperature, respectively 20 [°C];
- the convective heat transfer coefficients for the basement wall equal to 8.0 [W/m^2 K] and from the floor equal to 5.8 [W/m^2 K];
- along the sides boundary conditions: zero heat and moisture fluxes;
- the bottom boundary conditions, representing a ground water table depth of 9 [m], was maintained at a matric potential ψ = 0.0 m (i.e. saturated soil) and T = 10 [°C].

The concrete, gravel and insulation material properties used in the simulations are shown in Table 1.

Table 2 Material properties used for ground heat transfer simulations.

Material	thick. (cm)	ρ (kg/m^3)	k (W/mK)	cp (J/kgK)
Concrete floor	10	2400	1.7	840
Concrete wall	25	2400	1.7	840
Gravel	15	1800	1.5	840
Insulation	5	40	0.042	1460

The actual model and the mash that have been generated are shown in figure 2.

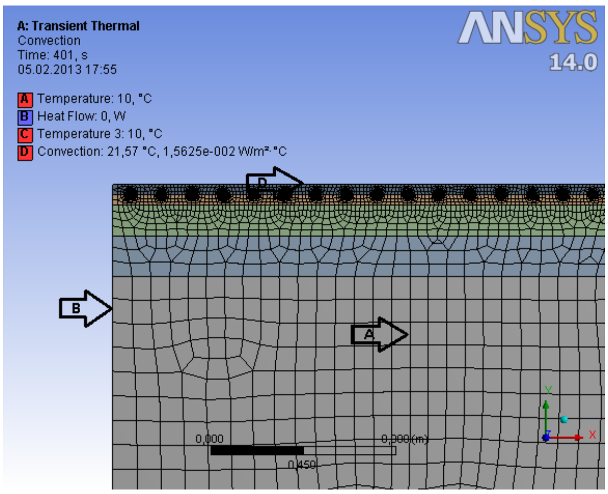

Fig. 2 Mesh and boundary conditions used for the heat transfer simulations.

The results obtained with the modeling software are similar with those obtained with the MC4 and

with those calculated using the EN 1264 calculus, namely the heat flux generated upwards of 69.2 W/m^2 during the period that we have simulated.
The heat flux generated downwards had a peek of 11.6 W/m^2.

The heat distribution in the underfloor heating system at the beginning of heating is shown in figure 3.

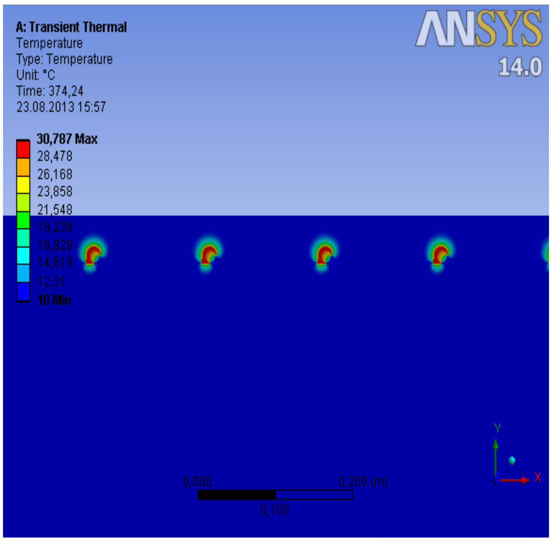

Fig. 3 The temperature in the underfloor heating system at the beginning of the heating period

5 Conclusion

Generally designers in Romania use in order to calculate such a system, computer programs that are available from the materials suppliers of the system.

Calculation methods presented in this article represents a more precisely instrument to calculate such a system. Therefore, the authors recommend it where sizing should be done more accurately. Respectively where the floor surface is small compared with the calculated heat load for the premises in question, or where thermal insulation and/or thermal inertia premises considered allows a reduction of investment costs with the tempered concrete or underfloor heating.

More than that, in the Civil Engineering Department are in development researches that are aimed at contributing to the expansion of knowledge in terms of dynamic behavior of both the underfloor and temperate concrete heating and cooling.

On the basis of the described methodology has been designed an underfloor heating system in the Low Radiant Temperature Heating Systems Laboratory. Table 1 show that the heat flux obtained with the above methodology was lower than the heat flux obtained with the MC4 SUITE HVAC CAD, which ensures that the designing processes are more accurate. That means the MC4 SUITE HVAC CAD will generate higher cost regarding the investment.

Also, the simulation revealed that the results obtained with the detailed calculus are very close of real conditions.

In our future work we will proceed to compare the results obtained with the 3D simulation with those measured in the laboratory.

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