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CASE STUDY

The Study of Heat Exchange between the Surrounding Environment and ” Heated Concrete” (TABS) System in a Laboratory Building – Study Case

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Abstract

This current paper intends to present the modeling of heat exchange between the surrounding environment and heated concrete on the basis of the ”virtual tube” method and Lumped Capacitance Method. The method has been researched in the laboratory of Radiation Heating of the Faculty of Building Engineering of the Transilvania University of Brasov where the measurements have been taken. Within the study, it has been aimed at determining the values of the temperatures in different points of the surfaces and of the average temperature by the method of the virtual tube and with these parameters we have evaluated the quantity of heat absorbed by the heated concrete from the inner space. We intend to highlight in the paper that the solution of passive cooling of the rooms with the heated concrete system represents a solution with good results in buildings with a reduced cooling thermal load due to the judicious choice of the building materials which make up the envelop-opaque elements and glass surfaces and we bring into discussion the issue of heat releases by men who stay in during the day and which can greatly be absorbed by this passive cooling system.

Keywords

virtual tube · thermal energy · cooling · heated concrete · heat capacity

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1 Introduction

This Radiant Panels used in heating or cooling systems presuppose the control of the temperature on their surface, temperature which is determined by the parameters of the used thermal agent. Panel heating and cooling system offer conditions of acceptable inner thermal comfort by the control of the temperature on their surface [1].

The low-temperature radiation system also called “heated concrete” represents a simple solution for the use of building elements as heating radiators, the heat transfer from the heating radiators to rooms being done mostly by radiation. The thermal agent pipes, transporting heated water, are inserted into the mass of the concrete at the level of floors, namely the floors of the rooms, the temperature of the thermal agent being under 30 °C [2]. The solution of heat accumulation in the mass of the building element, of the concrete, and its transfer towards rooms, represents a solution for increasing the thermal comfort within buildings and a technique for an efficient use of heat sources which make use of renewable energies [3] , [4]. Similarly, we can use the system called “heated concrete” in order to absorb the heat from rooms. In this situation, the thermal agent that circulates in the pipes inserted into the mass of the concrete is below 20 °C being influenced by the temperature of the dew drop inside rooms in order to avoid the formation of condensation on the surface.

The issue of heat transfer between the air and the heated concrete can be appreciated with acceptable, results by using the equation [1]:

$$q_c = 0,87\left(t_p - t_a\right)^{0,25}\left(t_p - t_a\right) \quad [W/m^2] \qquad (1)$$

Where t_a is the indoor air temperature and t_p is the mean temperature of the panel surface.

The heat taken from the inner air is at its turn absorbed by the thermal agent which circulates in the panel in this way succeeding in the cooling of the inner space [5].

In the IRDT of the Transilvania University of Braşov there have been implemented in a research laboratory a soil-water heat pump and a consuming radiation heating system called heated concrete – the thermal agent for the heated concrete is produced by the soil-water heat pump .The structure of the envelope was designed in such a way as to respond to the Directive which requires cuts on the energetic consumption of buildings. The accumulation of heat in ceiling / floors will ensure an efficient overtaking without any thermal variations of highest values during the heating period. For the summer period, the system heated concrete takes the heat from the inner space in this way ensuring the lowering of the inner temperature. The thermal agent which circulates in ceiling /floors takes over the heat absorbed from the environment and transfers it to the soil, ensuring in this way a passive cooling. The variation of the external temperature has a direct effect on the efficiency of the thermal pump since the functioning efficiency of the thermal pump is influenced by the thermal load of the building that at its turn depends on the exterior temperature [7, 8].

In the follow-up, we shall present a simplified calculation method of the temperature on the surface of the radiating plate called tempered concrete and we intend to obtain the calculation of the heat quantity absorbed from the inner space by the system heated concrete in an open space from a laboratory of ICDT Brasov where about 80 - 100 persons work.

2 Materials and methods

In this paper we intend to present:

1. The method of *virtual tube*, which allows of the calculation of the temperature in a point ***P*** of the building element (heated floor/ ceiling) around a ρ- radius tube, placed at a ***d*** distance from a ***S*** surface, maintained at a constant 0 °C temperature [1]. The calculation scheme by the method of the virtual tube is presented in Fig. 1:

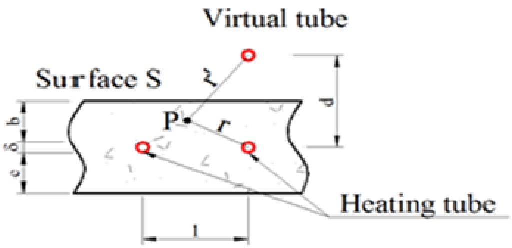

Fig. 1. The calculation scheme by the 'virtual tube' method

The temperature in the **P** point is calculated by the relation [1]:

$$t_p = \left(t_{mf}\right) ln\frac{r}{r'} / \left[ln\left(\frac{\rho}{2d}\right)\right] \tag{2}$$

where:

- t_{mf} average temperature of the cooling fluid, [°C];
- r distance from the P point to the center of the transversal section of the heating tube, in [m];
- r' distance from the P point to the center of the transversal section of the virtual tube, in [m];

The method of the virtual tube has been adopted in order to model the thermal radiation of the radiant floor by considering that the distance **d**, from Fig. 1, is equivalent to the sum of thermal resistances of the component strata situated above the heating tube to which is added the superficial resistance, Fig. 2. In this case, the constantly heated surface S is represented by the surrounding environment.

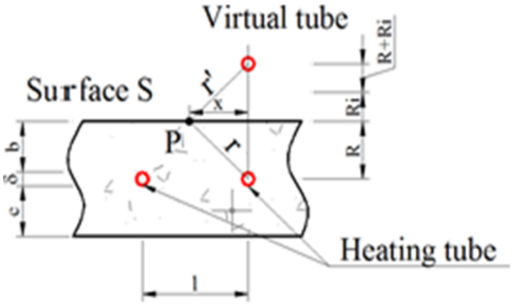

Fig. 2. The calculation scheme for the heated concrete by applying the method of the virtual tube

The temperature in the P point situated on the surface of the floor becomes [1]:

$$\begin{aligned} t_p &= t_i + ln\frac{r}{r'}\left(t_{mf} - t_i\right)/ln\left(\frac{\rho}{2d}\right) \\ r &= \sqrt{R^2 + x^2}, \\ r' &= \sqrt{(R + 2R_i)^2 + x^2}, \\ R_i &= \frac{1}{\alpha_i} \\ R &= \Sigma_{(j=1)}^{N} \equiv \delta_j/\lambda_j \end{aligned} \tag{3}$$

- t_i temperature of inner air, in [°C];
- R resistance to thermal permeability of the component strata of the floor situated above the tube, in [m^2K/W];
- R_i resistance to superficial thermal transfer at the level of internal surface, in [m^2K/W];
- α_i coefficient of superficial thermal transfer at the level of the internal surface, in [W /m^2K];
- δ_i thickness of the j stratum above the heating tube, in [m];
- λ_j thermal conductivity of the j stratum, in [W /mK];

The proposed numerical modeling permits the determination of the temperature of the plate's surface in any point of its points and in any point from inside. The thermal radiation of the plate is proportional to the temperature of the surface and to the temperature of the internal air. The temperature on the surface of the plate is not uniform, since it varies linearly with the distance to the vertical of the tube's section, as it results from the equations (2) and (3).

The average temperature of the plate's surface is calculated with the relation [6]:

$$t_{Pm} = \frac{1}{\frac{s}{2}} J_0^{\left(\frac{s}{2}\right)} \equiv \left[\left[\frac{t_i + \left(t_{mf} - t_i\right)}{\left(\frac{ln\rho}{(2(R+R_i))}\right)}\right] ln\frac{r}{r'}\right] dx \tag{4}$$

By integrating the above equation, we obtain [6]:

$$t_{PM} = \left[\frac{t_i + \left(t_{mf} + t_i\right)}{\left(ln\frac{\rho}{2}\left(R + R_i\right)\right)} \right] \frac{(A - B)}{s} \tag{5}$$

$$A = \left[\frac{s}{2} \ln\left(\frac{s^2}{4} + R\right) \right] - \left[s - \left(2arctg\frac{s}{2R}\right) \right] \tag{6}$$

$$\begin{aligned} B" &\left\{ \frac{s}{2} \ln\left[\left[s^{\frac{2}{4}}\right] + (R + R_i)^2\right] \right\} - \\ &- \left\{ s - \left[2\left(R - R_i\right) arctg\frac{s}{2}\left(R + R_i\right) \right] \right\} \end{aligned} \tag{7}$$

s distance between tubes, in [m].

2. The heat flux emitted by the radiating plate, which can be determined by obtaining satisfying results with the relation [1] both in the case of heating/ cooling floor and of the cooling ceiling :

$$\begin{aligned} q_c &= 0,87\left(t_p - t_a\right)^{0,25}\left(t_p - t_a\right) \ [W/m^2] \\ q_c &= 2,13 \mid t_{pm} - t_i \mid^{0,3} \left(t_{pm} - ti\right) \end{aligned} \tag{8}$$

Transient Conduction using the Lumped Capacitance Method; The lumped capacitance method is valid if Biotnumber,

$$B_i = (\alpha_i V) / (\lambda_i A_s) \ll 1 \tag{9}$$

α_i the convection convection heat transfer coefficient of the fluid (indoor air), [W /m^2K];
V volume of the cooling plate, (m^3);
A_s the surface area of the plate (m^2);

2.1 Constant temperature of the fluid

If the temperature may be considered uniform within the plate at any time the heat transfer rate at the plate surface is given by:

$$Q = \alpha_i A_s \left(T_m - T_i\right) Q = \rho V c_p \frac{dT}{dt} \tag{10}$$

T_m The average temperature of the plate (K);
T_i temperature of inner air (K);
ρ the density of the plate (kg/m^3);
C_p the heat capacity of the plate [J/(kgK)].
t time(s)

The temperature variation of the plate with time is:

$$\begin{aligned} [T]_m - T_i &= \left(T_{initial} - T_m\right) e^{(-\beta t)} \beta \\ [T]_m - T_i &= \frac{(\alpha_i A_s)}{\left(\rho V c_p\right)} \end{aligned} \tag{11}$$

The total heat transferred to the plate is :

$$[Q]_{total} = \rho V c_p \left(T_{initial} - T_m\right) \tag{12}$$

Q_{total} initial temperature of the plate(K).

If the temperature of inner air varies:

$$T = \frac{\left(\beta\left[\frac{1}{2}\left(T_{(i,max)} - T_{(i,min)}\right)\right]\right)}{\sqrt{(\omega^2 - \beta^2)} \cos\left[\omega t - [\tan]^{(-1)}\left(\frac{\omega}{\beta}\right)\right] + T_{(i,mean)}} \tag{13}$$

3 Results and discussion

The experimental determinations have taken place in the Laboratory of Radiation Heating Systems of the Faculty of Building Engineering. The measurement of the temperature on the surface of the plate in the laboratory has been done with sensors placed on the surface of the plate according to the detail in Fig. 3. The concrete plate where polyethylene pipes have been inserted is presented in Fig. 4. The measurements have been done in the interval 4.00 - 8.00. 221 values have been recorded for each sensor.

Fig. 3. The concrete plate for measurements

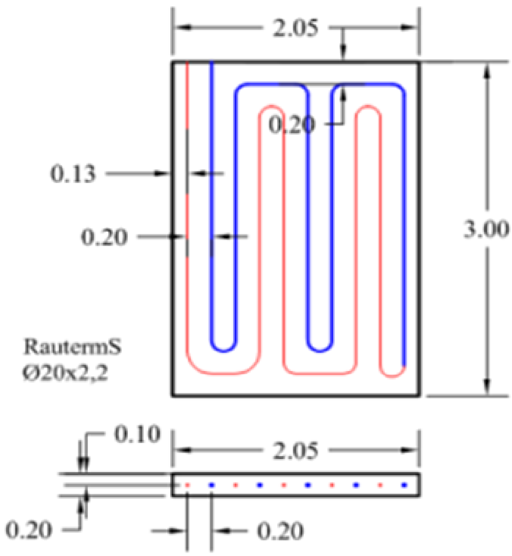

Fig. 4. Structure of the cooling plate

The result of the theoretical calculation according to the method of the virtual tube is represented below.

$$R = 0,05,$$

$R_i = 0,12$ for heating floor and

Tab. 1. Values measured in the laboratory for the temperature on the surface of the plate and of the temperature of the thermal agent / cooling agent

Sensor	Values in the interval Min Max °C °C		Interval centered values °C
S3.1	22,34	23,58	22,96
S3.2	22,65	23,89	23,27
S3.3	22,8	23,89	23,345
S3.4	22,49	23,58	23,035
S3.5	22,49	23,58	23,035
S3.6	22,49	23,42	22,955
S3.7	22,3	22,96	22,63
S3.8	22,03	22,65	22,34
S3.9	21,87	22,65	22,26

Tab. 2. Values measured in the laboratory for the temperature on the surface of the plate and of the temperature of the thermal agent / cooling agent

Sensor	Values in the interval Min Max °C °C		Interval centered values °C
S3.1	18.9	16.9	17.9
S3.2	18.65	17.55	18.10
S3.3	19.2	17.8	18.5
S3.4	19.6	18.2	18.9
S3.5	19.73	18.29	19.01
S3.6	19.9	18.5	19.20
S3.7	19.5	17.9	18.7
S3.8	19.3	18.4	18.85
S3.9	19.25	18.01	18.63

$R_i = 0{,}15$ for cooling floor, [$m^2 K/W$]

The d distance results:

$$d = 0.05 + 0.12,$$
$$d = 0.17\,m$$

The SCILAB program has been used for the determination of temperature on the surface of plate, as well as its average temperature by the method of the virtual tube for two hypotheses, as follows:

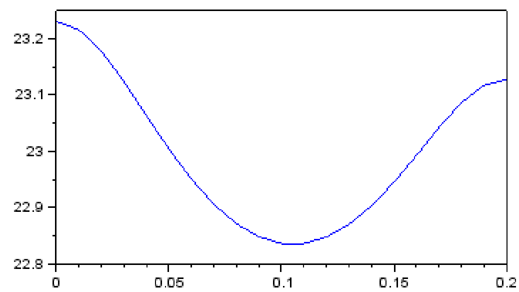

Fig. 5. Temperature graph

3.1 The variant when the radiating panel – heated concrete – gives away heat to the inner temperature

We have analyzed the situation of the plate in the laboratory according to Fig. 3 and by the help of the SCILAB program we have studied the method of the virtual tube, Fig. 2, the temperatures obtained on the plate for the central area where two tubes are positioned every 20 cm, by which thermal agent would circulate at the parameters:

- 23, 20647/inlet °C, 22,92489/outlet °C (Table 1),
- the temperature of the inner air is of 20 °C, coefficient $\alpha_t = 8$ are presented below: (Fig 5 and Table 5).

3.2 The variant in which the radiating panel –heated concrete – absorbs heat from the inner space

We have analyzed the situation of the plate in the laboratory according to Fig. 3 and by the help of the SCILAB program we have studied the method of the virtual tube, Fig. 2; the temperatures obtained on the plate for the central area where two tubes are positioned every 20 cm, by which cooling agent would circulate at the parameters: 17.4/inlet °C, 20.2/outlet °C (Table 1).

The temperature of the inner air is of $26\,C$, the coefficient $\alpha_t = 6,5$ [5], are presented below: (Fig 6 and Table 6)

By analyzing the results obtained above in laboratory conditions we intend to highlight that the solution of the passive cooling of the rooms with the system 'heated concrete' represents a solution with good results in buildings which have a reduced thermal cooling load due to the judicious choice of the building materials which make up the envelope – opaque elements and glass surfaces and we question the issue of heat release from humans who are there during the day and which can be greatly absorbed by this passive cooling system. We shall determine furthermore the quantity of heat absorbed by the tempered concrete in a room where the inner temperature is 26 °C due to the heat

Tab. 3. Values measured in the laboratory for the temperature on the surface of the plate and of the temperature of the thermal agent / heating agent

Thermal agent	Heated water	Heated water
No. measurements	221	221
Average temperature agent	23,20/inlet °C,	22,92/outlet °C

Tab. 4. Values measured in the laboratory for the temperature on the surface of the plate and of the temperature of the thermal agent / cooling agent

Thermal agent	Cold water	Cold water
No. measurements	221	221
Average temperature agent	17.4/inlet °C	20.2/outlet °C

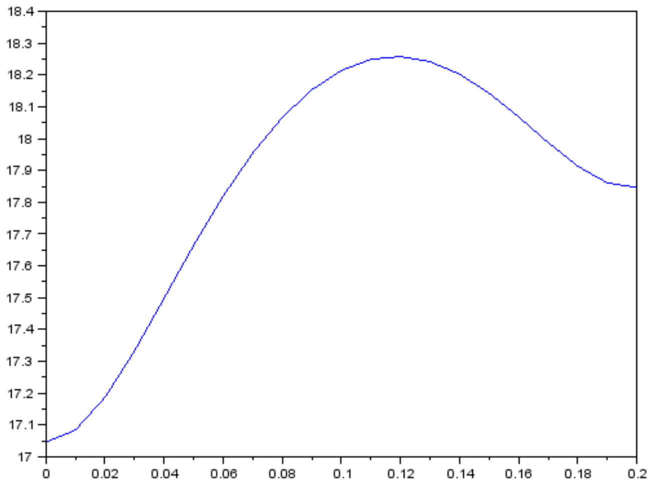

Fig. 6. Temperature graph

release from humans. The building represents a laboratory from ICDT Brasov where the heated concrete system has been implemented coupled with a passive cooling system (with the soil). The building has the following height regime: semi-basement, ground floor, and floor. The tempered concrete is made according to the schema - Fig. 4, in the three resistance plates of the building - Fig. 7, Fig. 8: over semi-basement, over ground floor, over the floor. Schema of the installation which does the passive cooling is represented in Fig. 9.

The surface of the open space is of 218.20 m². Daily, in this space there work about 80 researchers. Taking into consideration a heat release of 100 W / person, one can appreciate the heat quantity released by them, as being 8000 W. During the night, in the open space the temperature is of 20 °C and during the day due to the human contribution, the temperature increases to 25 °C. Under these conditions we have considered necessary to find a cooling solution of the open space, so that the activity in this space should not be disturbed. The solution applied is the passive cooling by the system "heated concrete". The system "heated concrete" is coupled to an installation of passive soil-water cooling, Fig. 9, made up of a water-water heat exchanger and 4100 m deep drillings. The estimated quantity of heat will be taken over by the system "heated concrete" [1].

$$q_c = 0,87\left(t_p - t_a\right)^{0,25}\left(t_p - t_a\right) \ \ [W/m]$$
$$Q = 27.37x218.20 = 5972 \ \ W/plate \tag{14}$$

$$q_c = 2,13 \mid t_{pm} - t_i \mid^{0,3}\left(t_{pm} - t_i\right) \ \ [W/m]$$
$$Q = 27,47x218.20 = 5995.58 \ \ W/plate \tag{15}$$

The total heat transferred to the plate by taking into consideration the initial average temperature on the surface of the plate obtained in the heating regime with the purpose of ensuring the comfort temperature and the final and average temperature in a cooling regime when there are human heat releases in the room:

$$\begin{aligned} Q_{total} &= \rho V c_p \left(T_{initial} - T_m\right) J \\ Q_{total} &= \rho V c_p \left(T_{initial} - T_m\right) = \\ &= 2.03 * 43.64 * 840 * (22.99 - 18.65) = \\ &= 322960.79 = 322961 J \end{aligned} \tag{16}$$

4 Conclusions

- By comparing the theoretical results obtained from the method of the virtual tube, hypothesis 2, with the values obtained by measurements, Table 1, we can conclude that the values are close, the method of the virtual tube can be considered appropriate for a theoretical establishment of temperatures on the radiant plate.
- The temperatures obtained on the surface of the plate under the conditions that we intend for the radiant plate to absorb the heat from the inner space are superior to the value of the dew drop, 17.64 °C, corresponding to the inner temperature of 26 °C and to the relative humidity of 60%. Thus the temperature of the cooling agent is of 17.4 / inletand 20.2 / outlet
- The establishment of the temperature of the thermal agent for any type of structure and going over that temperature value leads to values of the temperature in the intersection point between the surface of the floor and the vertical of the section of the tube's section superior to the admitted maximal value.
- The temperatures recorded on the radiant surface, the values recorded and the determinations presented above indicate that the radiant process under analysis is precise and possible;
- Given the concrete mass and if we take into consideration the heat accumulation in the mass of the element, it is possible

Tab. 5. Results of calculus

x	Tp	x	Tp
[m]	[°C]	[m]	[°C]
0	23,2302	0.11	22.8362
0.01	23,2158	0.12	22.8476
0.02	23,1776	0.13	22.8701
0.03	23.1238	0.14	22.903
0.04	23.0636	0.15	22.9447
0.05	23.0042	0.16	22.9926
0.06	22.9506	0.17	23.042
0.07	22.9058	0.18	23.0863
0.08	22.8713	0.19	23.1171
0.09	22.848	0.20	23.1269
0.10	22.8363		
Average temperature			22.990 °C

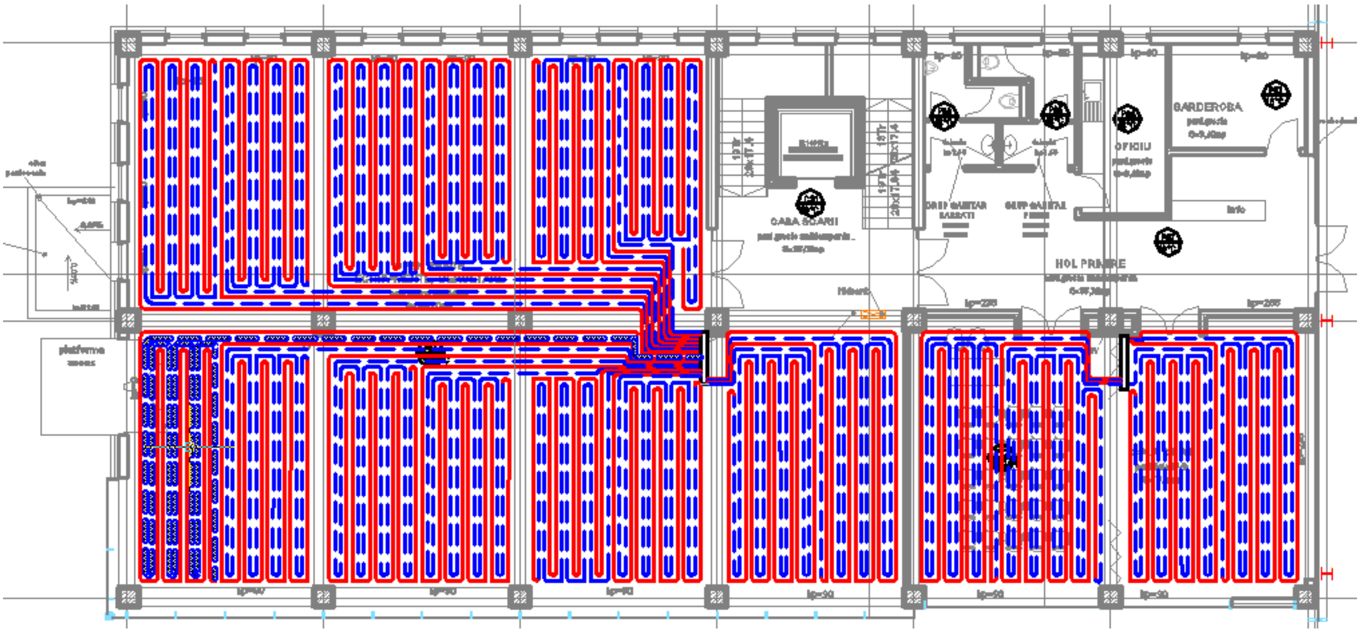

Fig. 7. Heated concrete on plate over the ground floor

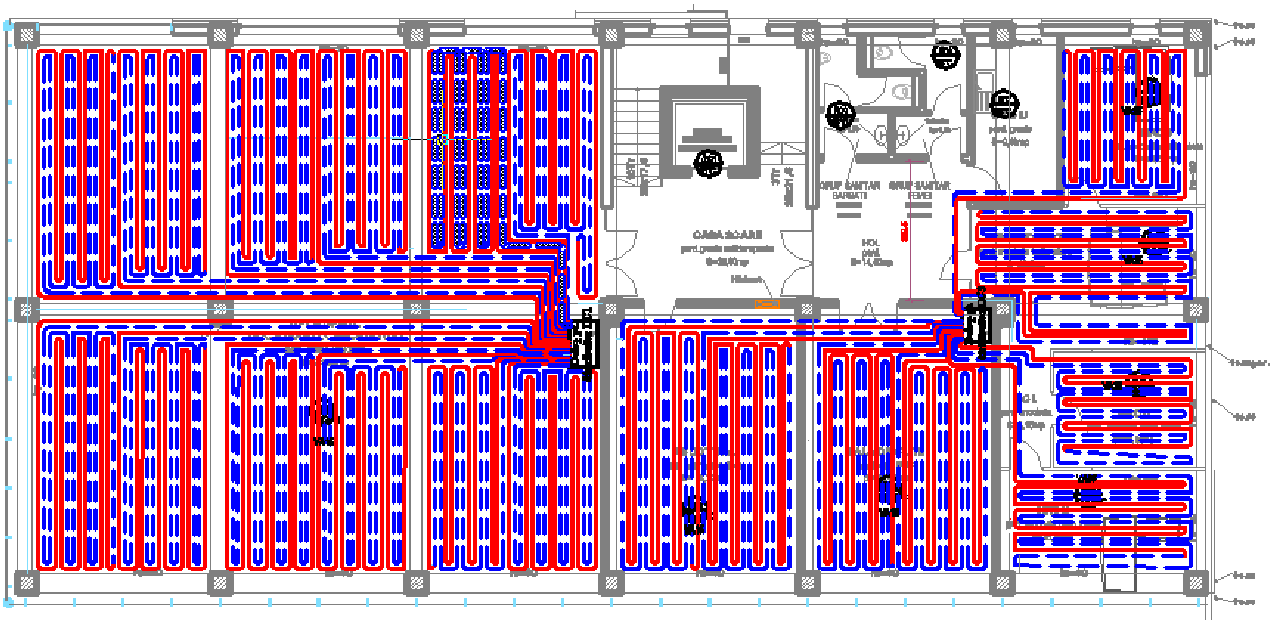

Fig. 8. Heated concrete on plate over the floor

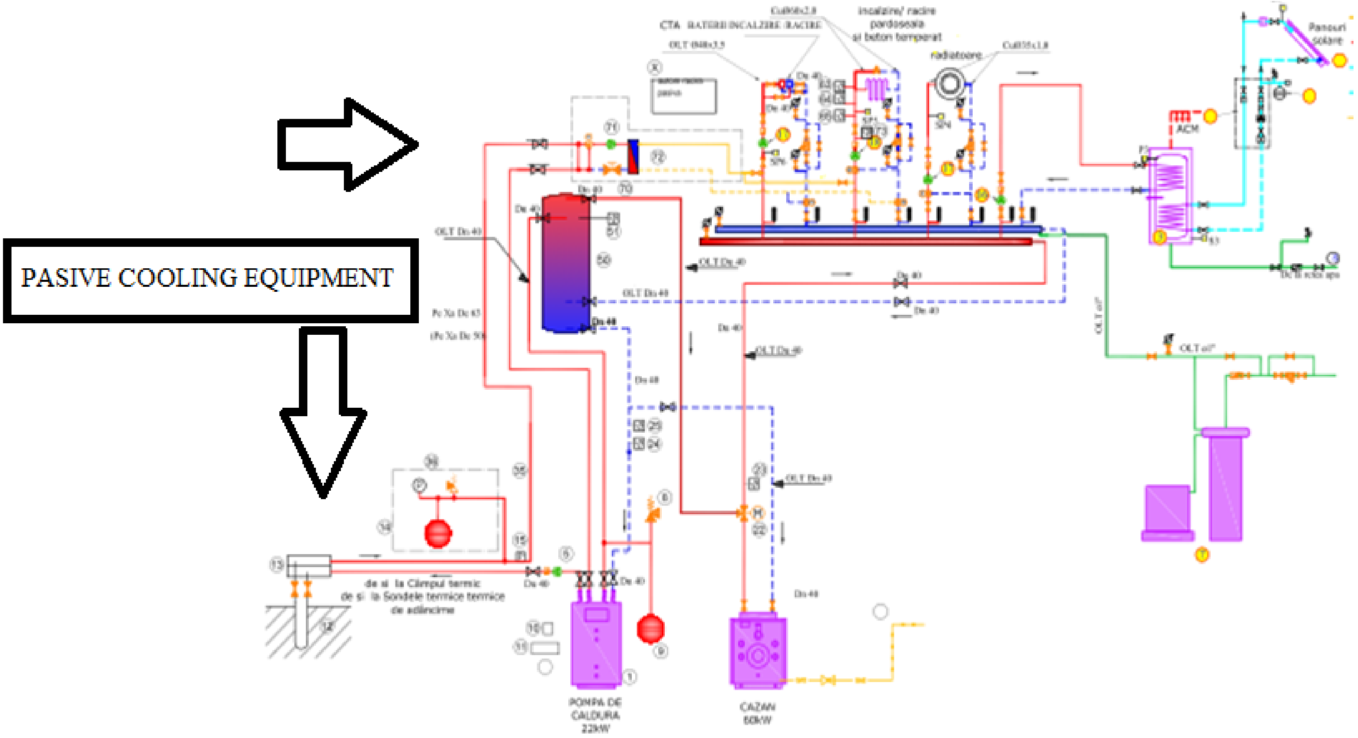

Fig. 9. Pasive cooling plant

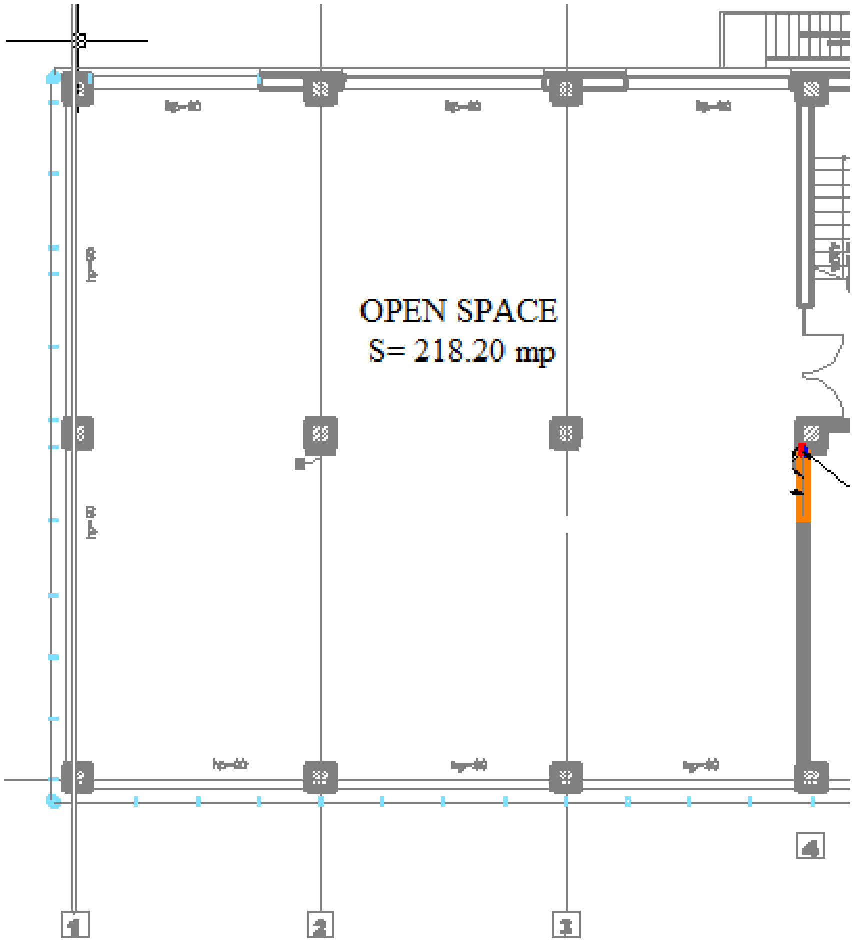

Fig. 10. Open space

Tab. 6. Results of calculus

x	Tp	x	Tp
[m]	[°C]	[m]	[°C]
0	17.046093	0.11	18.248979
0.01	17.084453	0.12	18.257774
0.02	17.187206	0.13	18.241625
0.03	17.333084	0.14	18.202194
0.04	17.498598	0.15	18.142505
0.05	17.664901	0.16	18.067847
0.06	17.819424	0.17	17.986924
0.07	17.954722	0.18	17.912625
0.08	18.066769	0.19	17.86092
0.09	18.153587	0.20	17.846236
0.10	18.214367		
Average temperature		17.867233 °C	

for the temperatures on the surface to level off, by concentrating all temperature values measured at very close values, therefore, a permanently precise process.

- The quantity of absorbed heat by the system of tempered concrete for the case under analysis (open space –laboratory ICDT , S = 218.20 mp, tempered concrete in the floor and tempered concrete in the ceiling, the situation of the floor) represents the heat quantity given away by humans. We conclude that the solution of passive cooling in the case of buildings with human heat releases represents an effective solution without further negative effects on the inhabitants.

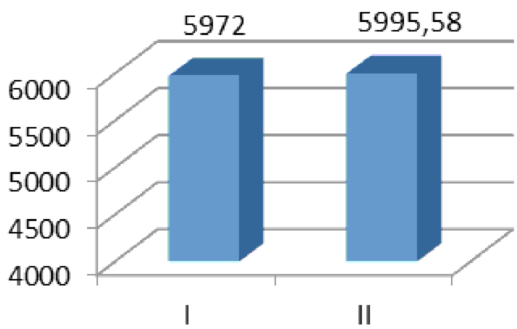

Fig. 11. Heat absorbed

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