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THE IMPACT OF DESIGN PARAMETERS ON THE COOLING PERFORMANCE OF TABS

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Abstract: *The paper highlights the influence of design parameters, such as pipe spacing, pipe diameter, type of floor covering, fluid flow regime and fluid flow temperature on the cooling performance of thermally activated building system (TABS). Considering the existing TABS developed in the Radiant Surface Laboratory of Civil Engineering Faculty of Brasov as a model a study based on a commercial simulation program (Comsol Multiphysics) was carried out. COMSOL Multiphysics® is a general-purpose software platform, based on advanced numerical methods, for modeling and simulating physics-based problems. With COMSOL Multiphysics, you will be able to account for coupled or multiphysics phenomena. The COMSOL Desktop® is a powerful integrated environment designed for cross-disciplinary product development with a unified workflow, regardless of the application area [7]. Results of the simulation and the conclusions are presented.*

Key words: *design parameters, cooling, TABS, simulations.*

1. Introduction

Reducing energy consumption in the residential and tertiary buildings is a matter of national interest being present all over the world. Today's energy consumption in buildings in developed countries accounts for approximately 30-50% of total energy consumption [3]. Significant problems of environmental pollution result from the burning of fossil fuels as the main source of energy needs. Energy-efficient cooling systems design is important from an environmental reason but for the lowering of the operating cost of buildings too.

Air-conditioning is the most common method worldwide used for summer comfort for residential and tertiary sector buildings. An energy efficient alternative is the mixed system based on radiation and on ventilation too, used for heating but also for cooling.

According to REHVA Guide [1] radiant surfaces used for low temperature heating and for high temperature cooling were divided into three categories:

- Radiant Cooling Panels (RCP),
- Water-based embedded cooling systems (ESCS),
- Thermally Activated Building Systems (TABS).

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The modern concept of TABS was developed by the Swiss engineer - Robert Meierhans in 1990 together with the architect Peter Zumthor, when designing two successful projects: the thermal bath at Vals in Switzerland (1996) and the Kunsthaus Bregenz in Bregenz, Austria (1997).

Energy consumption for cooling during peak load drops up to 42% in case of buildings equipped with TABS. In fact, this reduction varies between 17% and 42% depending on the climate in which it stands, cold and wet or hot and arid areas [26]. Currently there are several studies on the influence of design parameters on the performance of radiant systems. Sattari and Farhanieh [4] studied the effects of design parameters on the performance of a water-based embedded cooling system type ESCS using finite element method. Following studies showed that the main factor affecting the performance of the system is the type and the thickness of the coating.

Xing [6] studied the effects of thermal resistance of the pipe and that of the speed of the cooling agent on the performance of radiant floor, used for cooling. The thermal resistance of the pipe affects the performance of radiant floor only in case of vary low values, and the speed of the cooling agent does not significantly influence it even for laminar flow. Can et al. [2] studied the thermal flux of a capillary radiant floor for different values of the flow and of the cooling agent temperature. Studies have been conducted in particular on the ESCS-type radiating surface using the finite volume- and the finite element-method.

2. TABS simulation

Simulation was carried out on a TABS model identical to that existing in the experimental laboratory for radiating surface of the Civil Engineering Faculty from Brasov.

This model has the following constructive features: 6 sq.m area, thickness of 20 cm; the hydronic system having a length of 28 m is realized from a 20x2,2 mm pipe.

The heat is supplied to the hydronic system by a compression heat pump located in a Laboratory on the first level of the building. The same hydronic system is used during the summer for cooling the radiant laboratory, being fed by two absorption equipments, a chiller and a reversible heat pump.

Designing TABS is related to a selection of parameters:

- Constructive, like pipe spacing, type of floor covering and pipe diameter
- Operational, like flow rate and the temperature of the cooling agent.

The efficient operation of TABS is the result of their correct sizing.

Radiant surfaces used for cooling must comply for the necessary heat flux to be removed, but additionally their temperature should be over the dew point in order to avoid condensate.

The most important parameters which influence the temperature distribution on the radiant surface and the unitary radiant heat flux are:

- Pipe spacing,
- Fluid flow temperature,
- Fluid flow velocity (flow regime),
- Thermal properties of the covering surface,
- Pipe size.

The study of their influence was realized using the Comsol Multiphysics simulation software.

The PEXA pipe was considered in the middle of the TABS and the conductivities used for simulation were 2 W/mK for the concrete slab and 0.35 W/mK for the PEXA pipe. The heat transfer superficial coefficient for the TABS was 6 W/m^{2}K on its upper face, and 11 W/m^{2}K on its lower face respectively.

The indoor air temperature was considered constant at 26ºC for both spaces in contact with the upper and the lower faces of the TABS. This temperature lies within the comfort limits specified by the EN ISO 7730 standard [7].

Table 1 presents the parameters taken into account for each simulation case.

3. Results and discussion

The radiant heat flow and temperature distribution on the two faces of the radiant surface are the main parameters that influence its efficiency.

3.1. Pipe spacing

The most common method used to increase the radiant heat flow over TABS is the pipe spacing. Values of 15, 20, 25 30 cm for the pipe spacing have been used for simulating their influence on the radiant surface performance. Figure 1 shows the significant influence of the pipe spacing on the surface temperature on the upper and on the lower face of the TABS and on its uniform distribution.

The amplitude of the surface temperature rises with the pipe spacing. A difference of 1.8 C exists between a 30 cm pipe spacing and that of 15 cm.

However the influence of the pipe spacing is more significant for the heat flux over the radiating surface.

Obviously a smaller pipe spacing increase the value of the heat flux over the TABS. According to Figure 2 this increase is almost 40% in case of a 15 cm pipe spacing compared with the 30 cm pipe spacing.

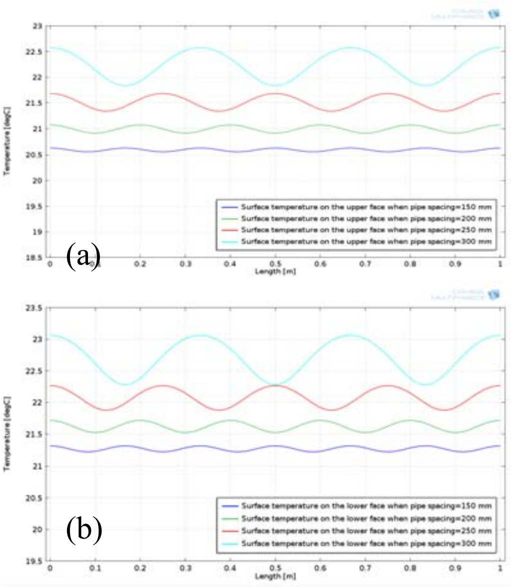

Fig. 1. *Surface temperature distribution on the upper (a) and on the lower face (b) of the TABS for different pipe spacing.*

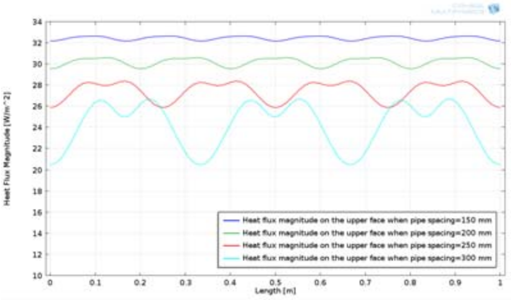

Fig.2. *Heat flux magnitude over the upper surface of the TABS for different pipe spacing.*

3.2. Pipe size

Two elements count when sizing the pipe for a TABS i.e. the diameter and the conductivity. Considering the fact that PEXA is the main material used for TABS only the pipe diameter is the selectable element.

In practice the size of the pipe is selected to correspond for a required flow of the cooling agent.

Figure 3 (a) and (b) show the influence of the pipe diameter on the temperature field and on the heat flux, respectively. As can be seen the size of the pipe affect to a lesser extent the temperature field of the radiant surface and the heat flux removed from the TABS.

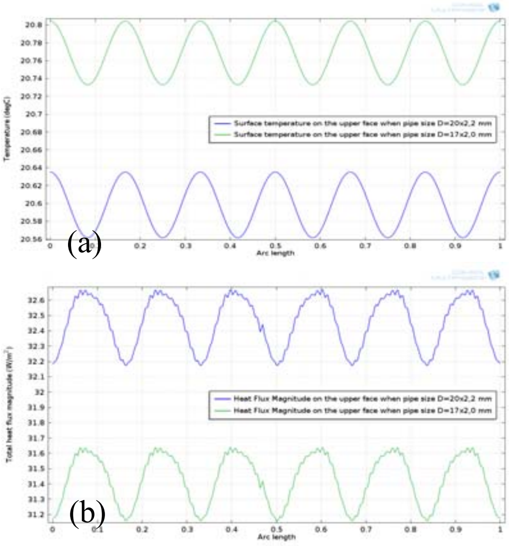

Fig. 3. *Surface temperature (a) and Heat flux magnitude (b) over the TABS for different pipe size.*

3.3. Flow regime

Usually heating and cooling by radiant surfaces is done using a turbulent flow resulting from the speed of the thermal agent, the hydraulic balancing elements playing an important role too.

To simulate the influence of turbulent versus laminar flow the Comsol Multiphysics software need the superficial heat transfer coefficient from fluid to the pipe wall. The following expressions [6] have been used:

Specific parameters for the investigated situations Table 1

Case	Pipe size	Fitting step	Fluid flow regime	Fluid flow temperature	Finished surface coverage
Influence of the fitting step	Ø 20X2,2 mm	0,15; 0,20; 0,25 and 0,30 mm	turbulent	16ºC	tiles
Pipe size	Ø 20X2,2 and Ø 17X2,0 mm	0,15	turbulent	16ºC	tiles
Fluid flow regime	Ø 20X2,2 mm	0,15	laminar and turbulent	16ºC	tiles
Fluid flow temperature	Ø 20X2,2 mm	0,15	turbulent	14, 16, 18, 20 ºC	tiles
Finished surface coverage	Ø 20X2,2 mm	0,15	turbulent	16ºC	tiles parquet PVC carpet and linoleum

- for turbulent flow:

$$\alpha_{turb} = 2040 \cdot (1 - 0{,}015 \cdot (T_{a.t} - 273)) \frac{v_{a.t}^{0{,}87}}{D_i^{0{,}13}} \qquad (1)$$

- for laminar flow:

$$\alpha_{lam} = \left(49028 + 4.173 \cdot \mathrm{Re} \cdot \mathrm{Pr} \cdot \frac{D_i}{l} \right)^{0{,}33} \cdot \frac{\lambda_{a.t}}{D_i} \qquad (2)$$

- for transitory flow

$$\alpha_{tran} = \alpha_{turb} \cdot \left(1 - \frac{1}{1 + e^{40 \cdot \left(\frac{v}{v_{tran}} - 1 \right)}} \right) + \alpha_{lam} \cdot \frac{1}{1 + e^{40 \cdot \left(\frac{v}{v_{tran}} - 1 \right)}} \quad (3)$$

$$v_{tran} = 2300 \cdot \frac{1{,}003 \cdot 10^{-6}}{D_i} \quad (4)$$

where

$T_{a.t}$ - fluid flow temperature, [K]

$v_{a.t}$ - cinematic viscosity of fluid flow, [m^2/s]

Re - Reynolds criterion

Pr - Prandtl criterion

$\lambda_{a.t}$ - thermal conductivity, [w/(m·K)]

L - pipe length [m].

D_i -.internal diameter[m]

To determine the thermal flux taken by the TABS, it is mandatory to know the convective heat transfer coefficient.

Using numerical methods for determining the convective heat transfer coefficient of the heat inside the pipe is a cumbersome method.

To simplify the calculation, was created a chart that is based on the above equations for the most common types of pipe used in TABS. As can be observed in Figure 4, in the laminar flow heat transfer coefficient from fluid to the pipe wall is approximately constant, varying significantly in the transitional and turbulent flow.

Figure 5 (a) and (b) shows the specific heat flux removed by the lower face of the TABS in case of laminar and turbulent flow.

The difference between the two situations is about 10% meaning that changing from laminar to turbulent flow has a low influence on the heat flux transferred by TABS.

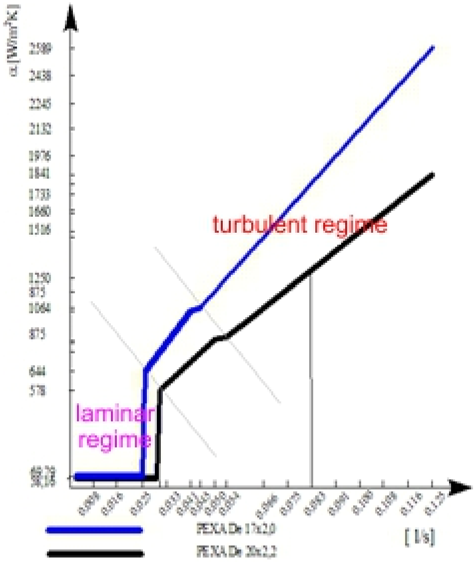

Fig. 4. *Convection coefficient variation based on fluid flow regime*

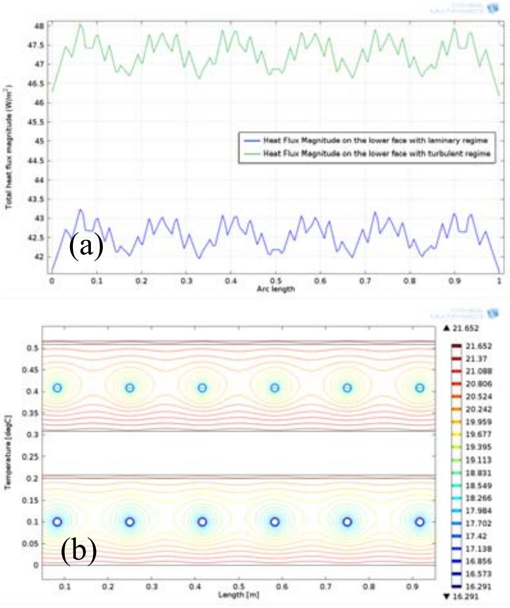

Fig.5. *The specific heat flux transferred by the lower face of the TABS (a) and temeprature distribution (b) in case of laminar and turbulent flow.*

The temperature field in a cross section of the TABS for laminar flow is similar with that for turbulent flow, as can be seen in Figure 6.

3.4. Covering surface

Thermal properties of the material covering the TABS have in significant impact on the temperature of the radiant surface and on the heat flux transferred by it. Four covering materials for the upper face of TABS have been studied – ceramic tiles, PVC-carpet, textiles and parquet. The performance of the TABS is in direct relation with the conductivity of the covering material. Figure 6 (a) and (b) shows the heat flux transferred by the TABS for the above mentioned types of covering materials. Ceramic tiles is the best covering material and PVC-carpet the worst-one when the heat flux transferred is considered.

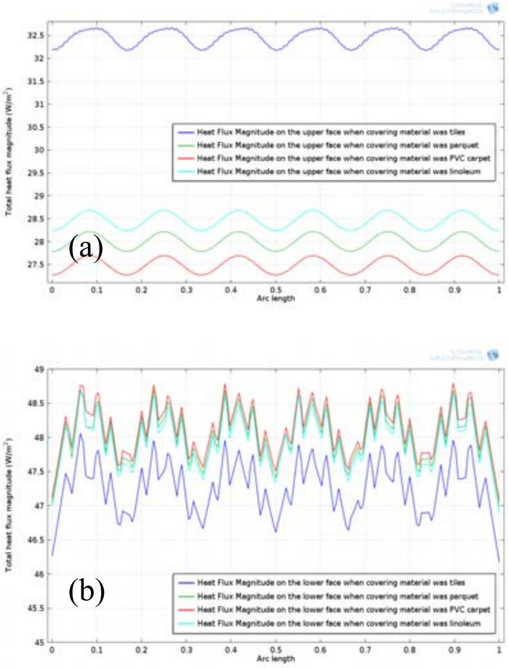

Fig.6. *Unitary heat flux transferred by the upper (a) and lower (b) face of the TABS for different covering materials.*

Figure 7 (a) presents the temperature distribution on the upper face of the radiant surface in case of the four covering materials considered for study. Ceramic tiles give the lowest surface temperature, and PVC-carpet the highest-one.

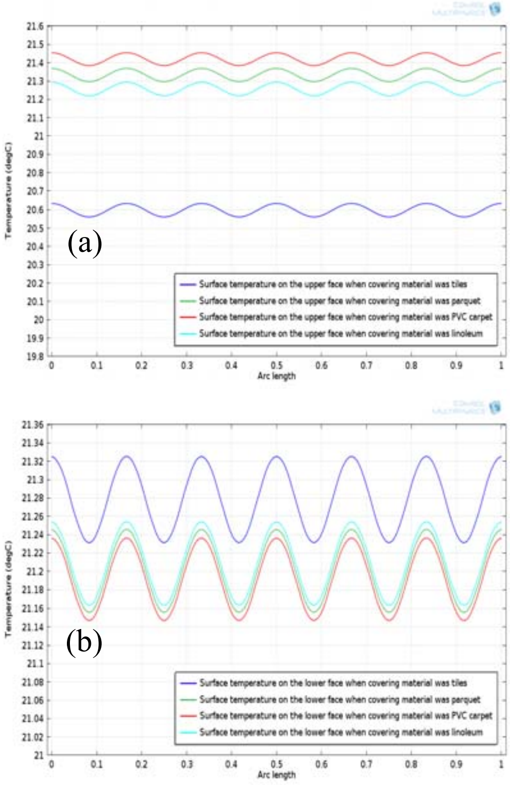

Fig. 7. *Temperature distribution on the upper (a) and on the lower (b) face of the TABS for different covering materials.*

The lower face of TABS is usually covered with a plaster layer. Figure 9 shows the impact of different covering materials used for the upper face of TABS on the heat transfer from its lower face.

As can be noticed the impact of the upper face covering material on the heat transfer is less than 5%, considering the best situation-PVC-carpet and worst-one i.e. ceramic tiles.

But the heat flux transferred in cooling mode by the lower face of TABS and 1.5 to 2 times higher than that transferred by the upper face.

Figure 7 (b) shows the temperature distribution on the lower face of TABS considering different types of covering materials for the upper face of the radiant surface.

Ceramic tiles as covering for the upper face present the highest temperatures for the lower face of TABS, and PVC-carpet gives the lowest temperatures for the lower face.

3.5. Cooling agent temperature

The best way to control the TABS operation is the temperature of the cooling agent. The heat flux removed by the TABS significantly rises when the cooling agent temperature is lowered i.e. the heat flux is twice if the cooling agent temperature is lessen from 20 to 14 °C, as Figure 8 shows.

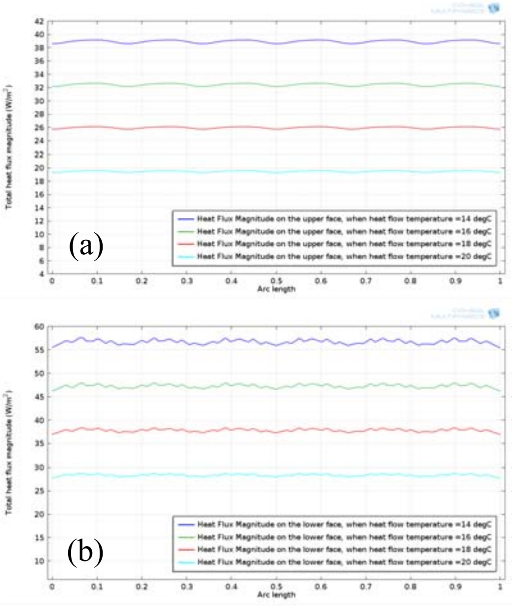

Fig.8. *The unitary heat flux taken over the upper (a) and lower (b) face of TABS for different values of the cooling agent temperature.*

Even if lowering of the cooling agent temperature is a very attractive issue from the point of view of the heat transferred by the radiant surface but its value is limited by the dew point.

Condensate on the surface of TABS must be avoided and comfort temperature is limited to 19 ºC in case of floors, European Standard EN 15377-2005 [7] recommending a lower limit of 17 ºC.

Figure 9 presents the impact of cooling agent temperature on the upper face temperature of the radiant surface.

For the temperature range considered in this case the cooling agent temperature $t_{cool.ag}$ could be correlated with the required upper face of TABS $t_{up.surf}$ with the expression

$$t_{cool.ag} = 1{,}8 \cdot t_{up\ surf} - 21{,}02 \quad [^{o}\mathrm{C}] \qquad (5)$$

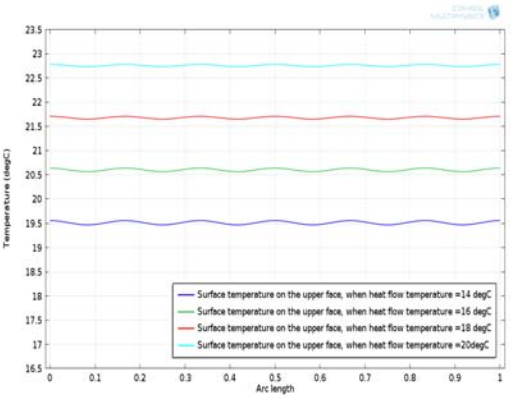

Fig.9. *Temperature distribution on the upper of TABS for different values of the cooling agent temperature.*

4. Conclusions

This study realized through simulation has shown the impact of different constructive and operational parameter on the performance of TABS indicating the issues to be selected for a better efficiency of this new technology.

Using larger pipes for the radiant surface does not improve significantly the performance of TABS, but rises the cost of the investment.

Lowering the speed of the cooling agent through the pipes do not affect substantially the performance of TABS, but the pressure losses lessen and a significant reducing of energy needed by circulators is possible.

Pipe spacing is the most important element to be used when designing a TABS in order to fit the cooling load of the system with the cooling requirements of the space

The covering surface of the upper face of TABS must be considered during the design phase as a result of its impact on the system operation.

The most important parameter for the performance and efficiency of TABS is the cooling agent temperature, but it must conform to recommended values in order to avoid condensate on the radiant surface.

These simulations, performed in stationary regime are intended to be a starting point for a more complex and time dependent future study. The results will be compared to the values from the laboratory's monitoring system.

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