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A study on the Effect of Cooling Capacity in Capillary Ceiling Radiant Cooling Panel by using different Shape Pipe Design & Parameters

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Abstract

In order to obtain surface temperature distributions and cooling capabilities, a computational fluid dynamics (CFD) simulation was carried out on the heat transfer of chilled water flow in the capillary of the ceiling radiant cooling panel. Capillary radiant panel circumstances and heat transfer performance were complicated by six elements, including chilled water intake parameters, gypsum plaster conditions, and capillary matting structural characteristics. Temperature profiles on ceiling panels may be evaluated using an index of temperature non-uniformity coefficient. The results of the simulation were compared with temperature variation and hydraulic power is calculated in terms of pressure in all 4 cases which are defined in form of different shapes of pipes and variation in gap between each pipe. Pipe having spiral shape with 20 mm spacing between each spirals have the best heat absorptions rate and this design obtain lowest temperature in ceiling which is 17.593.

Keywords: Radiant cooling, Ceiling design, Heat transfer, Pipe arrangements, Ceiling material, CFD, ANSYS, floor heating/cooling, spiral tube.

1. INTRODUCTION

The Residential heating applications basically contains tubes or electrical elements which are embedded in surfaces or ceilings. Figure explains the classic construction of subfloor, the pipes which

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are embedded in concrete or gypsum. On the top of the rafters (beams) pipes are installed. By accumulating metal heat transfer plates, heat diffusion as well as surface temperature can be enhanced and regulated which extended the heat underneath the finishing material. [1]

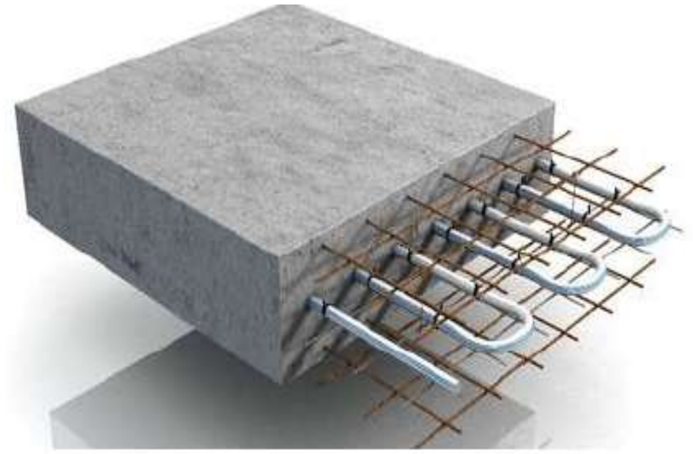

Figure 1: Embedded Pipes in concrete

To save the prospective energy as well as to improve thermal relief (constant cooling and heating supply) Radiant floor heating systems (RFH) is used, due to this RFH become popular. There are many benefits of Radiant floor heating systems (RFH). To increase the energy efficiency the hydronic panel systems might be arranged in a sequence. Radiant panels control the air temperature inside the building along with mean radiant temperature and reduce the air space inside it. Hence thermal comfort is more satisfying as compare to convectional air conditioning methods. Additionally the cost of radiant panel systems is low as compared to the convectional air conditioning system. [2]

1.1. Working Procedure of Radiant Cooling Panel Systems

In radiant cooling ceiling, the pipes are connected with the non – visible side of the panels containing chilled water, the chilled water is running throughout the pipes. The main use of ceiling panels is to exchange the heat between the air flow inside the room and the chilled water. By circulating cold water ceiling panels absorbed heat, which is coming from the heat sources in the room.[3] After absorb heat and circulating chilled water then this chilled water are driven to the chiller, cooled again and return to the ceiling. In radiant cooling ceiling system the heat flow is distinctive. The heat of people which is emitting inside the room is radiated towards the cool ceiling. To control the warmness of ceiling, chilled water is running in the ceiling.[4] The water carries the energy to the cooler [5]

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1.2. Applications of Radiant Cooling Panel System

As they are very common and easy to operate these Radiant cooling panel systems are generally used in the common buildings. These public buildings containing hospitals together with nursing homes including schools, libraries plus museums, as well as offices and various other buildings.[6] Radiant cooling panels can be mounted where it require.

2. LITERATURE REVIEW

(Jin et sl., "*Sustain. Cities Soc.",* 2020) [7] Surface condensation limits the use of radiant ceiling cooling panels. Supply water flow management and surface temperature variation are intimately linked, and this is a major element in condensation issues. In order to regulate the supply water flow, this article investigates the dynamic change in surface temperature. When the chilled water supply is shut off, condensation may be successfully avoided on the radiant ceiling panel surface. The average temperatures of the non-cooling surface, the interior air temperature, as well as the internal surface temperature of the outer windows are the three key elements influencing the surface temperature for fixed supply water flow. There is a 47.6%, 39.2%, and 10.1% contribution from each of these variables. The dynamic variations in surface temperature of radiant ceilings for closed water supply are modelled and confirmed on the basis of this study, and the findings match with the experimental results.

(Lim, Kang and Jeong, "*J. Build. Eng.",* 2020) [8] Phase change material (PCM) integrated thermoelectric radiant cooling panel (PCM-TERCP) design was the goal of this research. Thermal performance of the PCM-TERCP was studied numerically and experimentally. TEM, heat sinks, insulation, and a PCM layer sandwiched between two aluminium panels are the components of the PCM-TERCP design. As a thermal energy storage, the PCM layer freezes at peak demand periods to offer passive cooling without requiring TERCP to be operational at all times. Computer simulations were used to establish an ideal PCM layer structure for the proposed cooling panel. So, the panel's temperature could be maintained over the operating time without activating the TEMs. Measurement and data from the PCM-TERCP mock-up were used to verify the numerical model. Within the 10% error margin, the anticipated results were in agreement with the measured data. PCM-cooling TERCP's performance was studied using a parametric research to identify the most important design factors.

(Jobli et al., "*Appl. Therm. Eng.",* 2019) [9] With the goal of improving the interior thermal climate and reducing energy consumption, this research investigates a new system of Capillary Tubes embedded in a Phase Change Material (CT-PCM). Buildings' radiant heating and cooling systems and phase change materials may be used to optimise low-grade energy utilisation potential, according to the CT-PCM system. Experiments on thermal response are carried out on a CT-PCM component constructed in a laboratory to determine its thermal properties. In addition, a simplified model is built to evaluate the CT-PCM system's long-term thermal performance for use in a strategically designed system.

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(Li and Chen, "*Appl. Therm. Eng.",* 2019) [10] Thermal environment and heat consumption of a room with varied radiation end laying types are studied in this work in order to investigate how cross-household heat transfer affects excellent indoor thermal environment and building energy efficiency. The surface temperature and overall heat consumption of the inner wall are directly affected by the temperature of the surrounding room. A 2.3–3.7 percent reduction in heating surface temperature, a 15.3–16.3 percent increase in heat flux density for floor and ceiling heating, and a 22 percent reduction in heating surface temperature due to the substantial heat transfer to neighbouring rooms via internal walls were observed.

(Plytaria *et al.*, "*Energy Convers. Manag.",* 2019) [11]This work was investigated for the energy and financial purpose, in which the estimation of energy saving capacity and the total capital invested over the construction of building which include solar cooling system along with radiant walls which comprises Phase Change Materials (PCMs). The building which is used to studies the installation of solar cooling radiation system containing the area of 100 m^2 is situated in Athens in Greece. To produce cold water which intend for the radiant walls of building, to join the single effect absorption chiller tied along with evacuated tube collectors to solar cooling system.

(Zhou *et al.*, "*Energy Build.",* 2019) [12] Radiant heating and cooling system displayed a disproportionate radiant symmetry, even though many scholars explore this topic to examine the effects of thermal comfort along with the uneven symmetrical effect of radiant environments. The exposure duration particularly in floor heating plus cooling scenarios has not been highlighted. This study concluded that the test series conducted in a climatic chamber along with the floor cooling radiant asymmetries to study the effect of thermal comfort from short-term (2h) and long-term (8h) exposure views. A test conducted on 2 h exposure specifies the more complaints of discomfort in floor cooling system than other radiant systems it has strong cooling effects to cool the floor rapidly.

3. METHODOLOGY

3.1. Steps of Methodology

The experiment has been carried out through the numerical simulation of the radiant cooling system. The complete methodology includes model design and CFD analysis of the same. While the modeling was done using the CATIA V5 software, for the numerical analysis ANSYS has been employed. The steps involved in the complete numerical simulation of the radiant cooling are as follows:

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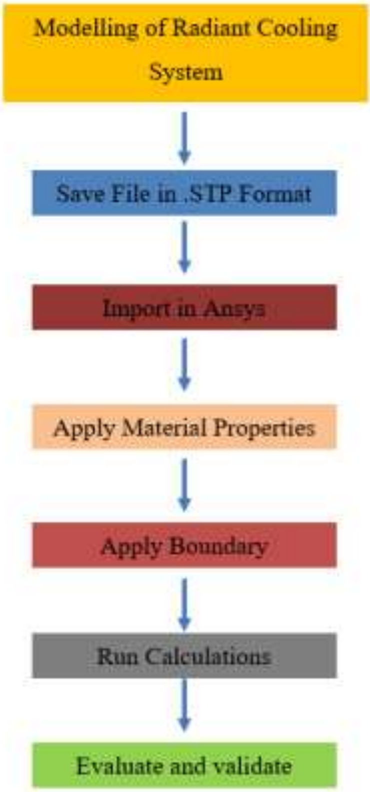

Figure 2: Working Methodology

3.2. Material property

A gypsum plaster solid was used to fill in the spaces left by the capillary tubes, which were assumed to be fluid in the physical model.

The property of Water, Aluminium and Gypsum is determined with respect to their thermal conductivity, density and specific heat and their separate values are listed in table below:

Table 1: Properties of water liquid

Properties	**Value**
Thermal conductivity$(Wm^{-1}K^{-1})$	0.75
Density (Kg/m^3)	998.2
Specific heat(J/KgK)	4182

Table 2: Properties of gypsum plaster

Properties	**Value**
Thermal conductivity$(Wm^{-1}K^{-1})$	0.50
Density (Kg/m^3)	836.4
Specific heat(J/KgK)	950

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Table 3: Properties of aluminium

Properties	**Value**
Thermal conductivity($Wm^{-1}K^{-1}$)	900
Density (Kg/m^3)	2719
Specific heat(J/KgK)	871

3.3. Model design

- (Length)L= 2000 mm
- Width = 120 mm
- (Tube spacing)W= 20 mm
- (Tube diameter)a= 4 mm
- (gypsum plaster)δ= 10 mm

4. RESULTS AND DISCUSSION

4.1. Case-1 Validation design

Design is validated with the base paper which is selected for study, variation of maximum (19°C) and minimum (16°C) temperature is same in both results.

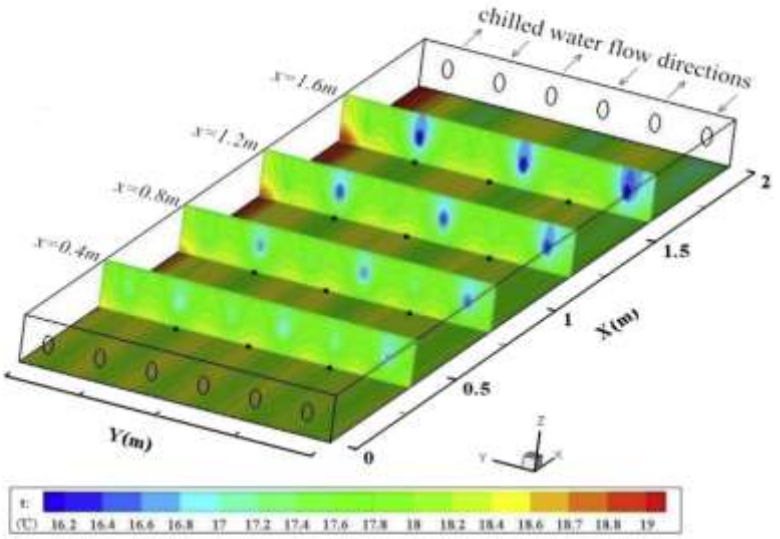

Figure 3: Result of paper

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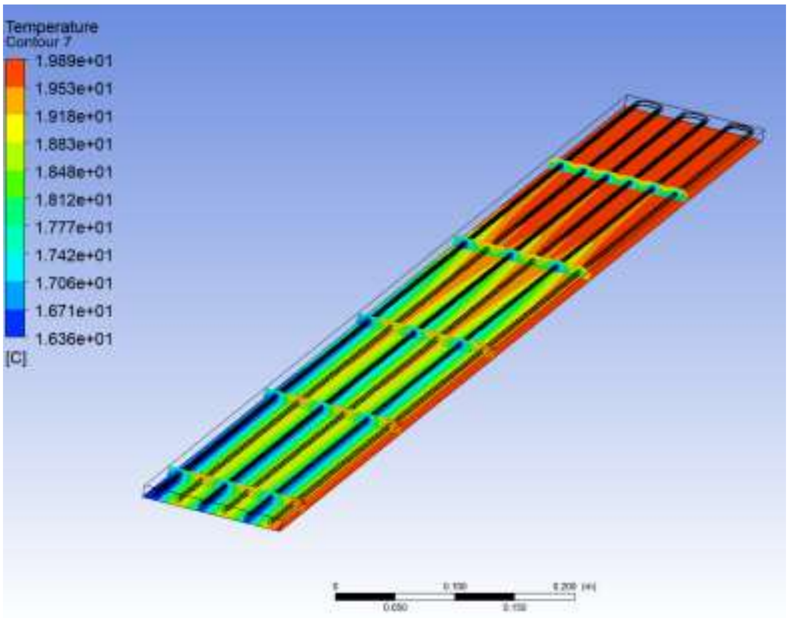

Figure 4: Temperature variation in different planes

4.2. Case-2 Linear pipe with 10 mm spacing

Below figure shows variation in temperature of linear pipe which were placed inside of gypsum plaster. Maximum and minimum temperature is observed as 19.75℃ and 16℃ respectively.

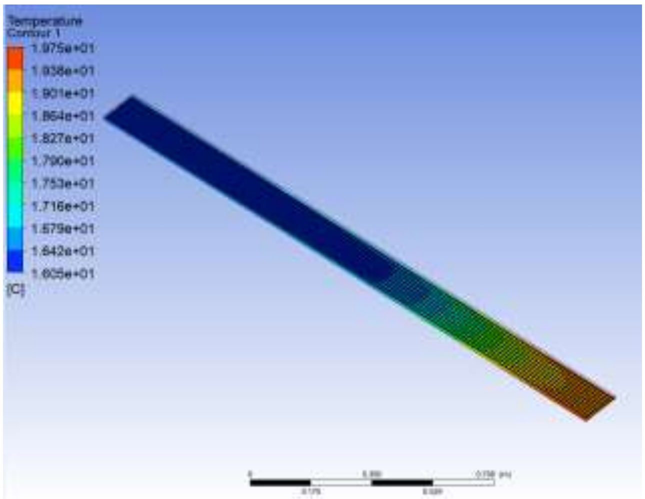

Figure 5: Temperature variation in linear pipe

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4.3. Case-3 U tube pipes with 40 mm spacing

Below figure shows variation in temperature of U tube pipes with having 40 mm spacing in between pipes, which were placed inside of gypsum plaster. Maximum and minimum temperature is observed as 22.2℃ and 16℃ respectively. Here blue colour shows low temperature and red colour shows higher temperature, higher temperature can be observed at all outlet area of spiral pipes.

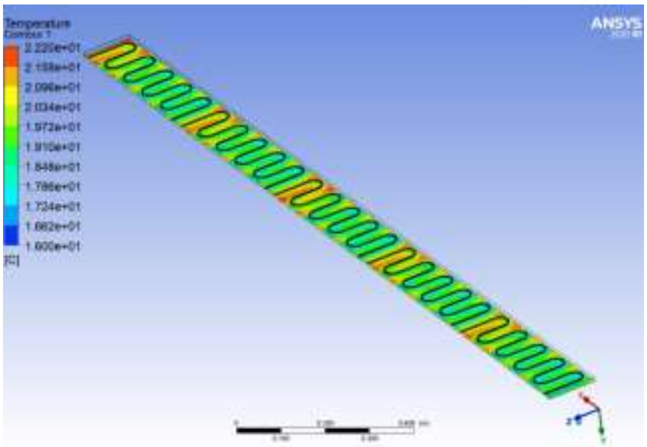

Figure 6: Temperature variation in spiral pipe with 40 mm spacing

4.4. Case-4 U tube pipes with 20 mm spacing

By analysing above U tube pipes case result, it was seen that spacing of pipe have wide impact on managing temperature because less spacing means it will cover more gypsum plaster area. So for this case spacing of pipes was reduced to 20 mm and results are defining in below figure:

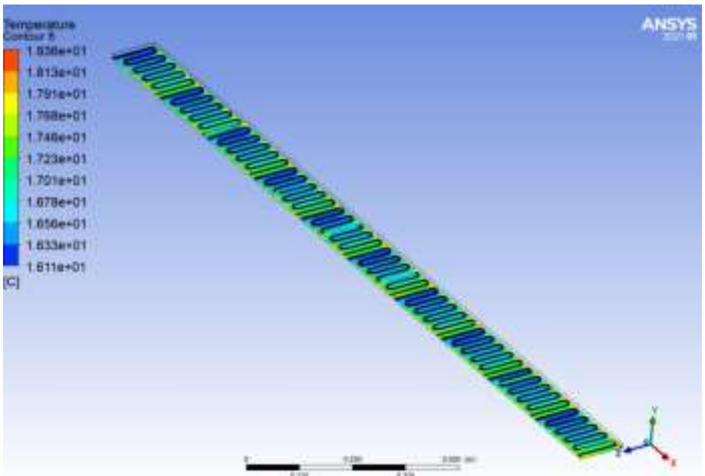

Figure 7: Temperature variation in spiral pipe with 20 mm spacing

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Below mentioned graph is representing outlet temperature obtained by fluid inside pipes in all cases. And it shows that case 4 which is having spiral tubes with 20 mm spacing between pipes shows the best result because it got heated less from all others. Case 1, case 2, case 3 have 19.229℃, 19.196℃, and 19.33℃ respectively. Which are almost same for all 3 cases whereas case 4 has 17.593℃. it is defining that spacing of pipes shows important role in keeping the gypsum plaster and fluid temperature cool.

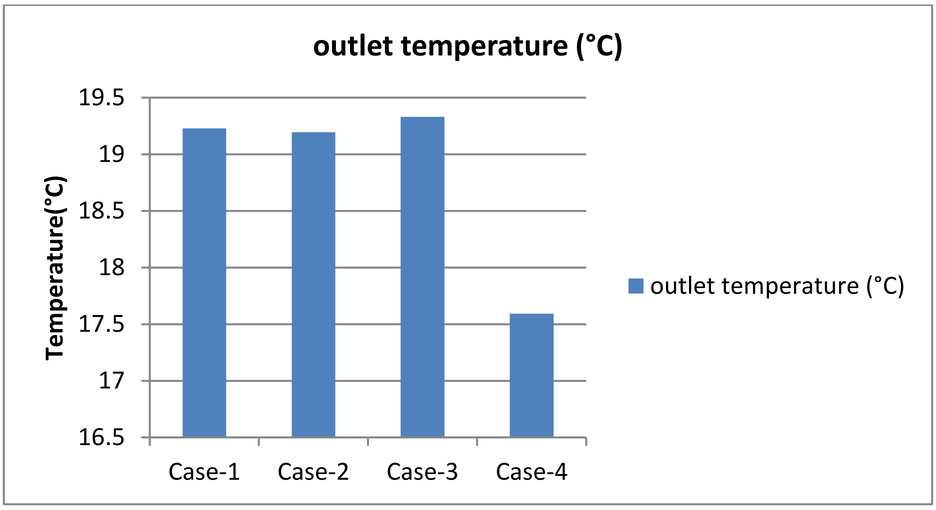

Figure 8: Temperature comparison in all cases

4.5. Power calculation

Pressure variation in all cases

Table 4: Value of pressure at inlet and outlet in all cases

Case	Inlet pressure(P1)	Outlet pressure(P2)
Validate	920.96	0
Linear	486.68	0
U tubes- 40	313.23	0
U tubes-20	290.82	0

Validation case

$$P_1 = 920.96\ Pa$$
$$P_2 = 0\ Pa$$

Inlet pipe diameter (d) = 4 mm

Velocity (v) = 0.1 m/sec

Discharge (Q) for each pipe

Q = $A \times V = \frac{\pi}{4} \times d^2 \times V$

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$=\frac{\pi}{4} \times (0.004)^2 \times 0.1 = 12.56 \times 10^{-7} m^3/sec$

Number of inlet pipes in validation case = 3

Total discharge = $Q_T = \sum_{n=1}^{3} Q_n = 3 \times 12.56 \times 10^{-7}$

$$= 37.68 \times 10^{-7} m^3/sec$$

Hydraulic power (P)= $Q \times P$

$$= 37.68 \times 10^{-7} \times 920.96$$

$$3.47 \times 10^{-3} watt$$

Table 5: Hydraulic power in all cases

Case	**Hydraulic power (watt)**
Validate	3.47×10^{-3}
Linear	6.72×10^{-3}
U tubes- 40	1.96×10^{-3}
U tubes- 20	3.65×10^{-3}

Above mentioned table is defining hydraulic power which is calculated by formula. And it is a multiplication of discharge (Q) and pressure difference (P).

5. CONCLUSION

As the radiant cooling system has a good potential for energy saving as compared to conventional cooling system, this study is based on the design and performance improvement of ceiling radiant cooling system which can be used for any house, or building without installation of conventional HVAC. Out of the 4 different designs of the radiant cooling system that has been compared in this thesis, the U tube cooling system with 20mm spacing between the tubes has given the best results and the lowest outlet temperature of 17.593℃. The inlet pressure is also minimum in this case, i.e., 290.82 Pi and the hydraulic power is 3.65 x 10^{-3} watts.

As an alternative to completely air-conditioned office buildings, thermally active building components – or simply thermo active components – are a viable option. There must be a careful evaluation of the system's performance and improvement in order to execute them effectively. Rooms are cooled evenly and without any draughts or noises, making them more comfortable. As a result, additional research and evaluation is necessary for the betterment of the globe.

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