Thermal performance evaluation of radiant panel applying microchannel heat exchanger based on numerical analysis

マイクロチャネル熱交換器を用いた放射空調の数値解析による放熱性能評価

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Abstract: This paper studies a new type of metal cooling radiant panel applying microchannels(MCRCP).A heat transfer analysis model of MCRCP was created by ANSYS to analyze the thermal performance. Radiant panels with different designs are simulated to evaluate their thermal performance and temperature distribution. Finally, the performance of MCRCP with the indoor testing is conducted.

1. Introduction

Research on ceiling radiant cooling panel (CRCP) systems has been widely conducted in Japan and overseas. Based on the review, to enhance the overall performance of the CRCP, a lower thermal resistances between the cold water and the outer surfaces of the panel is of great importance. And the panel must consume a lower pumping power and realize a uniform temperature distribution [1]. Finally, it is promising to integrate the open-type CRCP in the conditioned room.

Therefore, the originality of this research work is based on two main aspects. First, a new microchannel-based CRCP is proposed. Different designs of this panel are compared at the same condition. Second, the designed microchannel CRCP is tested using the standard testing method for the CRCP. The indoor heat transfer coefficients, and the indoor temperature distribution were computationally estimated. The designs of the CRCP proposed in this work accomplished an increased airflow and heat exchange between the plenum zone and the room zone. A series of 3D computational models have been developed in this work. The CFD models were validated by comparing the predicted results with the results in the literature.

2. Outline and advantages

The ceiling radiant cooling panel applying microchannel (MCRCP) has the following advantages:-

- Heat exchanger can be arranged at an angle to the header pipe on the MCRCP system. It means that the area of the cold wall can be much larger than the traditional panels, and the cooling capacity can be dramatically increased for the same panel coverage area.
- Traditional CRCP usually made by metal materials, such as aluminum. MCRCP can be made by metal or plastic. Therefore, the material cost can be reduced.
- The heat transfer coefficient from the cold water to the panel surface in the MCRCP increases due to the decrease in the channel sizes. And the pumping power decreases because of increasing the flow area compared with the tube and sheet conventional design [2].
- The panel cooling load can be increased using a fan.
- Traditional CRCP system use water as a cooling medium. However, MCRCP can use refrigerant directly. So, the cost can be reduced for total system.

3. Theoretical analysis

In this paper, a heat transfer analysis model of MCRCP was created by ANSYS to analyze the thermal performance. The thermal performance analysis of different designs of the MCRCP were computationally evaluated. And the performance of MCRCP with the indoor testing is conducted.

3.1. Performance evaluation of single panel

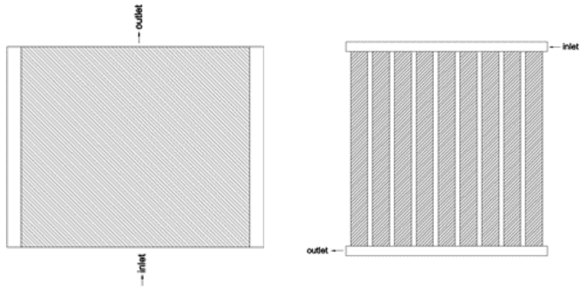
In this section, radiant panel model with different designs were simulated. To evaluate the thermal performance and temperature distribution.

3.1.1. Traditional single segment CRCP and multi segmented MCRCP

To compare the cooling capacity and temperature distribution of two designs of radiant panels depicted in Fig. 1, a three-dimensional model of the radiating plate was established. To save the calculation costs, the header pipe in both cases were designed as a flat tube with the same thickness as the panel. First, two cases were compared. Case A is a flat single unit MCRCP, and case B is multi segments of MCRCP. As shown in Fig. 1 and Table 1.

Table1. parameters of case A and B

	Case A	Case B
dimension [mm]	800×900× 1	70× 800×1
No. of segments	1	9
Total panel area [m^2]	0.72	0.5704



(A) Single segment MCRCP (B) multi segment MCRCP

Fig.1. Radiation panel of different shapes

In these cases, the water inlet temperature was considered at 15℃, and same flow rate was set for both cases. The total heat transfer coefficients due to the surface radiation and convection on the panel surfaces was 10.8 W/m^2 K with indoor environment at temperature of 25℃ [3]. The two cases are compared at three flowrates, and the result are shown in Table 2. It is noticed that case A shows a higher cooling capacity and better temperature distribution compared to case B. This may be attributed to the reduction in the panel surfaces area for the case B.

Table2. Cooling capacity, Q, panel temperature, T_p, and panel temperature uniformity, ΔT of case A and B

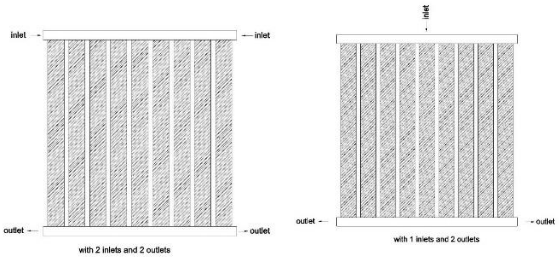
	Case A			Case B		
	Q	Tp	ΔT	Q	Tp	ΔT
[L/min]	[W]	[°C]	[°C]	[W]	[°C]	[°C]
0.576	57.639	15.867	1.659	26.77	19.689	9.221
3.456	61.716	15.202	0.492	43.92	16.224	3.627
5.76	62.055	15.147	0.37	46.04	15.79	2.447

However, the single segment traditional CRCP is a horizontal plane that is mounted under the ceiling of the room. The heat exchange areas are the same for radiation and convection and they were limited by the ceiling area or panel coverage area. This means that it is impossible to improve the thermal performance of case A without changing the ceiling area at the same operation conditions. On the other hand, the cooling capacity of the multi segment MCRCP can be improved by simultaneous change of the inclination angle and the number of the segments. But the problem of non-uniform temperature distribution must be solved first. Therefore, several flow filed designs for the multi segment MCRCP in the next subsection.

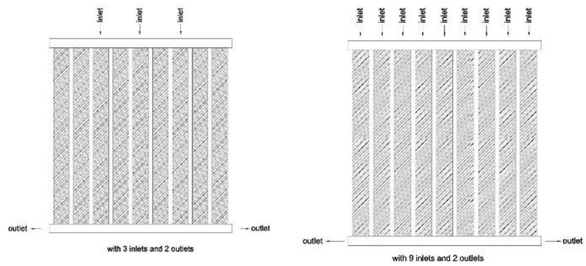
3.1.2. Enhancing the panel temperature uniformity of the multisegmented MCRCP.

We suspect that the non-uniform temperature distribution may be related to water flow mode. In order to solve this problem, four different designs of flow mode were proposed for the multi segmented MCRCP. These designs depends on varying the cold-water supply location. These designs includes (i) water supply at the two inlets; (ii) water supply at the upper single inlet; (iii) water supply at the three upper inlet locations; and (iv) water supply at multiple upper nine inlets as shown in Fig. 2 respectively. The total inlet flow rate for these four cases was 0.24 L/ min. In the case of more than one inlet, the flow is evenly distributed at each inlet. The water supply temperature is still at 15 °C. For all of cases are laminar flow. The simulation results and data analysis are shown in Fig. 3 and Table 3.

It can be seen from the results that under the same boundary conditions, the four cases are almost have the same cooling capacity except for the case(i), which suffer from a lower cooling capacity than others. Table 3 shows the cooling capacity and average surface temperature of different cases. Also, case (ii) is the best solution with regards to the panel temperature uniformity. Under the same cooling capacity, by changing the direction of water supply, the surface temperature can become more uniform. This is very helpful to avoid the local condensation problem caused by uneven temperature distribution [4].

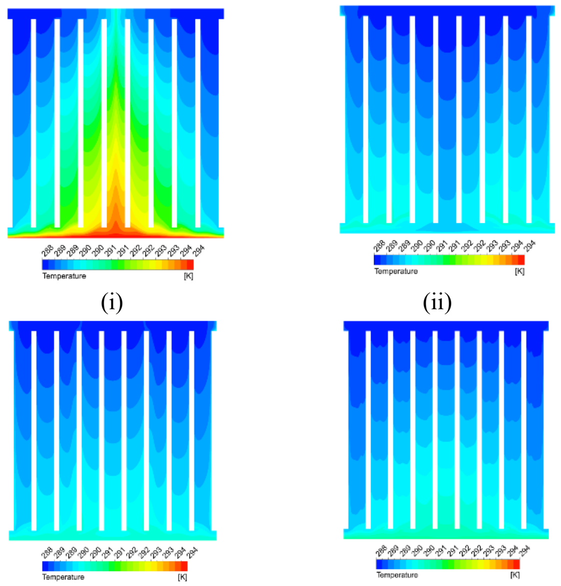


(i) (ii)



(iii) (iv)

Fig.2. Radiation panel with different flow mode



(i) (ii) (iii) (iv)

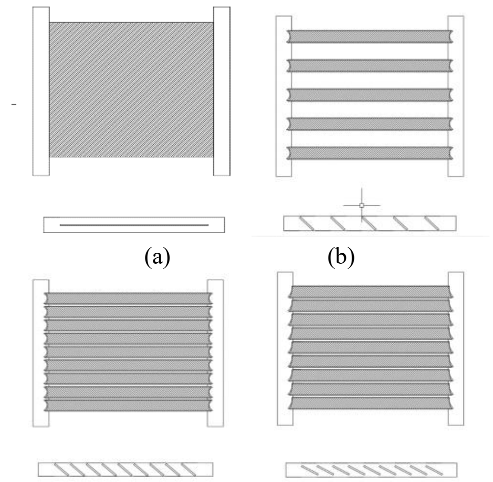
Fig.3. Temperature distribution for different flow mode

Table3. Cooling capacity and temperature of case i, ii, iii, iv

	Flow rate	$\dot{Q}$ [W]	T_p [°C]	T_{max} [°C]	T_{min} [°C]	ΔT [°C]
i		40.505	16.918	21.210	15.014	6.196
ii	0.24	45.657	15.868	16.899	15.013	1.886
iii	L/min	45.592	15.881	17.033	15.019	2.013
iv		45.364	15.928	17.460	15.030	2.430

3.1.3. Radiant panel with tilt angle

In order to further analyze the influence of the shape of the radiant panel on the thermal performance, three kinds of panels with inclined angles were simulated to compare with the flat plate model with the same area as seen in Fig. 4. In these cases, the header pipes of all cases are designed with round tubes to mimic the realistic conditions. The way to supply water is to enter the bottom right, and to flow out of the top left after flowing through the panel. Laminar flow with considering the gravity effect was simulated. Based on the simulation results, Table 4 compares the predicted panel temperature, cooling capacity, panel maximum and minimum temperature, and panel temperature uniformity. It is noticed that the cooling capacity can be significantly increased can be seen in case (c) due to the increase in the panel area. This increase in the panel area can't be accomplished with the conventional single segmented panel case (a). In addition, the temperature uniformity on the panel surface is around 1.5 ºC. and the minimum temperature for all cases is nearly constant closer to the water inlet temperature.



(a) (b) (c) (d)

Fig.4. (a) flat panel with ingle segment; (b) panels with 45º tilt and 5 segments; (c) panels with 45º tilt and 9 segments; and (d) panels with 60º tilt and 9 channels.

Table 4 Cooling capacity and temperature of case a, b, c, d

case	T_p [°C]	T_{max} [°C]	T_{min} [°C]	ΔT [°C]	Q [W]	surface area [m^2]	q [w/m^2]
a	15.4	16.2	15.03	1.1	25.2	0.298	84.4
b	15.3	16.1	15.03	1.1	34.6	0.408	84.7
c	15.5	16.6	15.03	1.51	44.7	0.536	83.3
d	15.5	16.6	15.03	1.6	44.5	0.536	82.9

The multisegmented design can be used with larger areas. To confirm this, the panel (c) is compared with the single segmented panel in the standard testing conditions resented in Fig.5 and detailed explained in a 3D simulation for the room including the panel was conducted[2,3]. Turbulent flow with S2S radiation model is used to estimate the convention and radiation exchange inside the room. The panel kept at uniform temperature of 15.8 ºC and the dummy cylinders at a constant heat flux of 113 W/m^2. Two cases were compared as seen in Fig. 6. In the MCRCP, the segments were inclined at angle of ± 45º. The area of inclined design was 1.8 times in the first case.

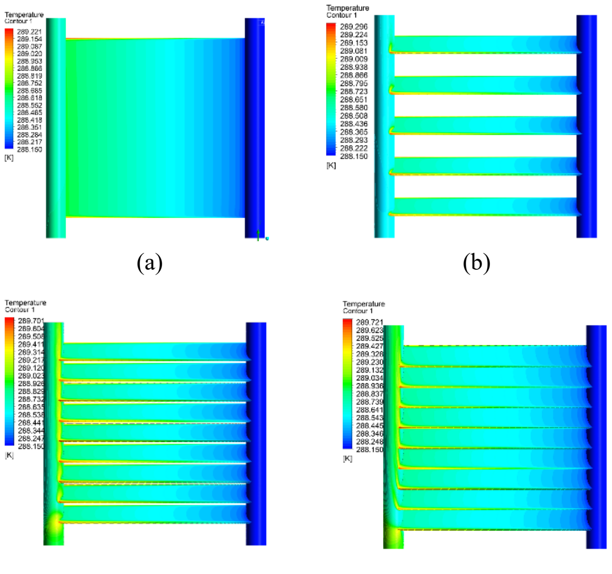


Fig.5. Temperature distribution for different cases a, b, c, and d

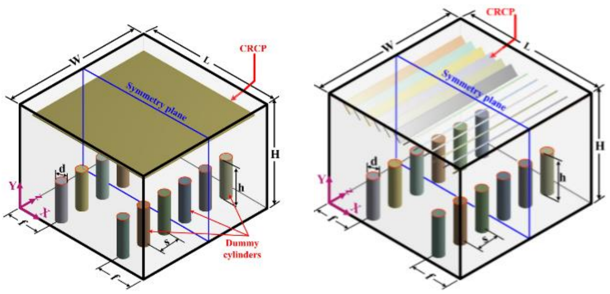


Fig. 6. Reference case (left) and Inclined MCRCP (right)

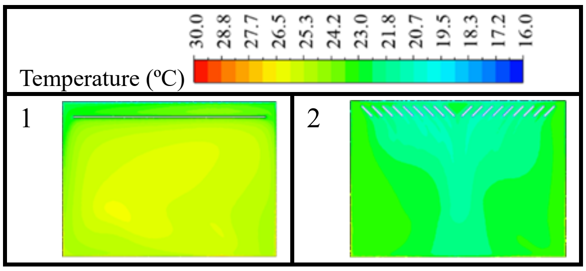


Fig.7 Temperatures contours at the plans in the simulated room at different cases.

Figure 7 shows the temperatures contours at symmetry plan in the simulated room for the two cases. The modified inclined MCRCP attained lower room temperature. Furthermore, the local temperature distributions on one line located at the middle of the room showed a significant reduction in the room temperature as in Fig. 8. This confirm that the modified design can be used for higher cooling capacity for the same indoor temperature.

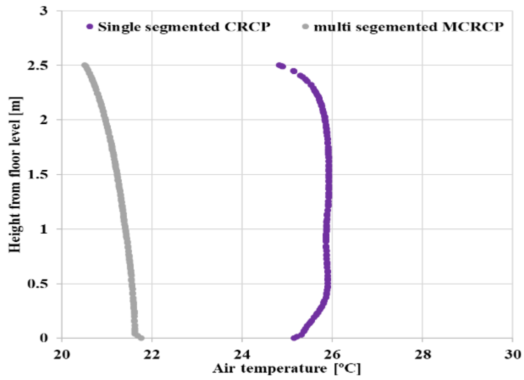


Fig.8 Local temperature distributions on a line located at the middle of the room

4. Conclusions

This paper studies a new type of metal cooling radiant panel applying microchannels. The MCRCP is composed of inclined panels in order to increase heat area. It can be concluded that:-

1) Temperature distribution of MCRCP can be adjusted by changing the inlet position of the water supply.
2) The cooling capacity is proportional to the area of the radiant panel. The system using MCRCP can add more panels by changing the installation angle, thereby achieving the purpose of improving cooling capacity.
3) Finally, the multi segmented MCRCP can be used to manipulate a wide range of cooling capacities.

References

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