Numerical Simulation of Thermal Comfort Degree in Radiant Floor Cooling Room

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ABSTRACT

As a comfortable and energy-efficient air conditioning system, the application of radiant floor heating system is increasing greatly used in the north of China. Now, more and more people begin to be aware of the problem of thermal comfort degree in radiant floor cooling room. This study aims at developing a radiant floor cooling system using the existing radiant floor heating system. Unlike an all-air cooling system, the radiant floor cooling system could remove the cooling by convection and radiation. To analyze the performance of a floor cooling system, simulation of convection and radiation was used. The thermal environment of the model office space was analyzed using CFD method. Two typical air distribution forms (hybrid air cooling system composed of radiant floor cooling and displacement ventilation and all-air system) was simulated. Installing two human models in the office, the characteristics of heat transportation from the human model were also analyzed. The analysis deals with only sensible heat in this study. The simulated results showed that the operative temperature in the radiant floor cooling system was lower than in the all-air cooling system when each of the sensible cooling loads of the two types of HVAC system was the same. In conclusion, two air distribution forms can meet the demand of comfortable degree of occupants and the effect of radiant floor cooling system.[1]

KEYWORDS

Radiant floor cooling; Displacement ventilation; CFD; Airflow distribution

INTRODUCTION

In the north of China, radiant floor heating systems are widely used to heat buildings, but very few systems are also used for cooling purposes. Reasons such as vertical air temperature difference, condensation and cooling capacity made people be anxious for efficient of a radiant floor cooling system. For a radiant floor heating system, more than half the thermal energy emitted from the floor is in the form of radiant heat. The convective heat from a floor heating system is delivered directly to the occupied zone at floor level, where the occupants are. The radiant heat exchange directly influences the heat exchange with the occupants and surrounding surfaces such as walls and ceilings. In this way thermal environment is uniform. Due to the high radiant heat output and the fact that the occupants are close to the floor, the same floor system obviously could also be used for cooling. The convective heat exchange coefficient for floor cooling is, however, much lower than for heating. There are several comfort factors, such as acceptable floor temperature, vertical air temperature and dew-point temperature, which may reduce the cooling capacity of a floor radiant cooling system. In the same time, the floor temperature should not be lower than 19℃ for comfort reasons, and must be higher than dew point to avoid condensation on the cooling surface [1]. Therefore, the radiant floor cooling system alone cannot provide enough cooling capacity in hot and humid weather. To solve this problem, radiant floor cooling combined with displacement ventilation system was proposed as an alternative approach. The radiant floor cooling system may take most of the sensible load, while the air system will take care of

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the latent load and the rest part of the sensible load. The displacement system brings dehumidified fresh air from outside to meet the minimum requirement for occupants. It appears that the relatively cold air from the supply inlet is first spreading horizontally upon the floor, forming a layer of cool carpet, and then slowly rising to the ceiling exhaust outlet when heated by various heat sources. The air flow near the exterior windows rises causing by the higher wall temperature. The heated objects, such as the photocopier, the computer and the occupants, generate strong plumes that bring the air from the lower zone to the upper zone. At the same time, the dew point in the space will lowered near the cooling floor surface and cooling capacity of a radiant floor cooling system may be enhanced.

The purpose of this study was to analyze the performance of a radiant floor cooling system using simulation (CFD) of convection and radiation. Unlike an all-air cooling system, the radiant floor cooling system could remove the cooling load by convection and radiation. To evaluate the performance of the proposed hybrid system, the thermal environment of the model office space, which is cooled by hybrid system composed of radiant floor cooling and displacement ventilation and all-air cooling system, was analyzed using CFD. Installing human models in the office, the characteristics of heat transportation from the human model were also analyzed. Since the temperature of cooling floor surface is not lower than the dew point in order to avoid condensation, the analysis deals with only sensible heat. By comparing the simulation results of the both systems, the performance of a radiant floor cooling integrated with displacement system was evaluated.

SIMULATION

Physical model

Analysis, using CFD, of the indoor thermal environment of an office space cooled by a radiant floor cooling system combined with displacement ventilation system was then conducted. The other case where the space was cooled by all-air types of HVAC system was also analyzed based on the same methods. Results were then compared and examined. In this study, an analysis of only sensible heat was conducted. The office space analyzed is shown in Figure 1. Two human models were installed in the room for quantitative analysis of indoor thermal environment. The east wall and west wall were exterior walls, and there was a window on the west wall. The other walls were heat-adiabatic walls. The supply inlet was set in the bottom of the south wall, and the exhaust outlets were on the top of the east wall and west wall. Two human models which generate 60 W each were installed in the room.

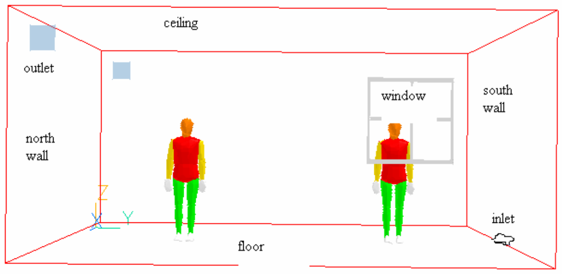


Figure 1 Office space for numerical simulation

Simulation of indoor air flow was conducted based on a zero-equation turbulent model. This model is more effective to predict natural convection, forced convection, mixed convection and displacement ventilation in a room. Compared with the $k-\varepsilon$ model, the zero-equation model used much less computer memory and the computer speed is at 10 times faster. Simulation results agree well with experimental data, which is to be reported in another paper.

Cases for analysis are shown in table 1. The radiant cooling floor and supply inlet were used in case 1. The airflow rate of the supply inlet is small and the radiant floor cooling surface removes most of the cooling load for the room. In case 2, only the supply inlet was used. In the two cases, the total cooling load was the same. The lower the operative temperature was on the human model, the higher the efficiency.

Table 1 Cases of analysis

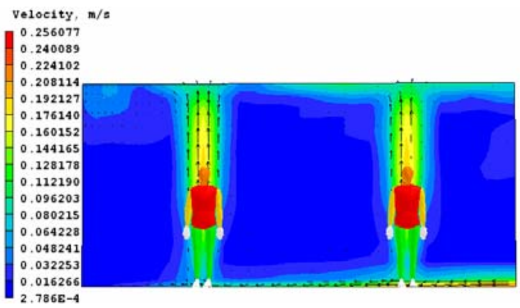
case	1	2
Types of air conditioning	Radiant floor cooling +	All air cooling system

system	ventilation	
Radiant floor load [W]	1029	—
Air conditioning system	Air flow from floor	Air flow from floor
Air supply temperature[℃]	20	21.4
Air flow [m^3/s]	72	498
Velocity [m/s]	0.20	1.38
Cooling load [W]	145	1174

RESULTS OF ANALYSIS

Airflow distribution

Air flow distribution in each case is shown in Figure 2. In case 1, the relatively cold air from the supplying inlet is first spreading upon the floor, forming a layer of cool and dry carpet. And then slowly rises when heated by heat source, such as occupants in the room. Thus strong plumes are generated to bring the air from the lower zone to the upper zone. The interior walls are of about the same temperature as the adjacent room air, because the adjacent rooms are under very similar indoor temperature. Near the window, the airflow ascended. Wind velocity was less than 0.05 m/s at occupant zones. In case 2, the airflow blowing from the floor supply inlet flowed human model at high velocity. Because wind velocity was largely faster than that in case 1, strong plumes cannot formed.



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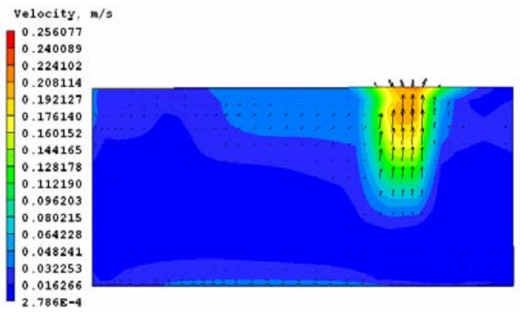
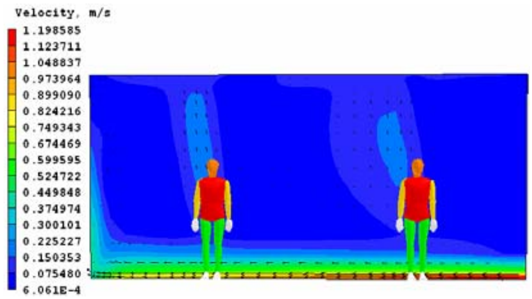
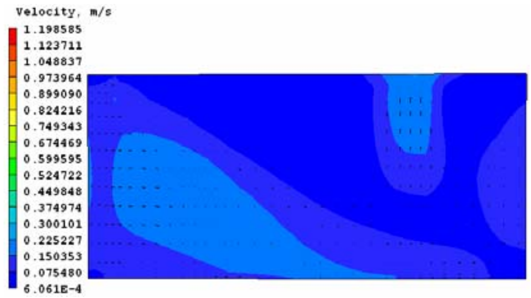


(a) X=4.9m



(b) X=2.5m

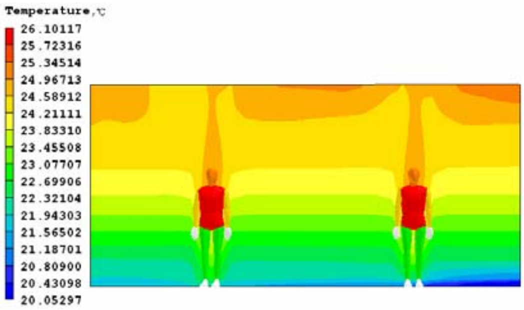


(b) X=4.9m

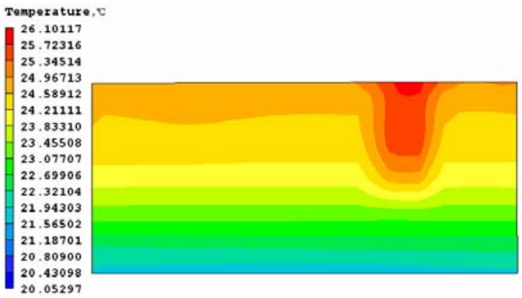
Figure 2 velocity distribution: (a) case1; (b)case 2

Temperature distribution

Temperature distribution in each case is shown in figure 3. In case 1, vertical temperature distribution had an obvious delaminating because the airflow from the supply inlet did not disturb the indoor air. Air temperature was about 24.5-25℃ near the human model. In case 2, a large temperature gradient was observed near the floor. Near the human model, the air temperature was 23-25℃, relatively uniform because the moving air stirred the air in the room.



(a) X=2.5m



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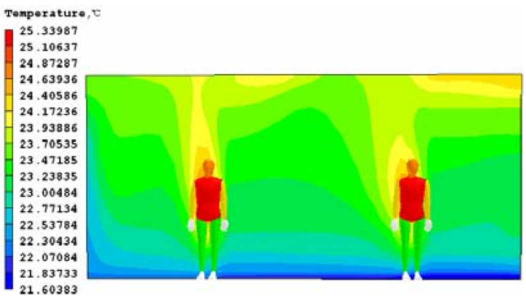

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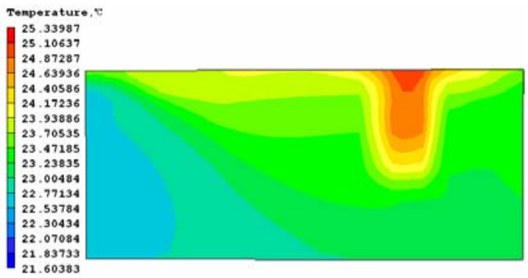

(b) X=4.9m

Figure 3 temperature distribution: (a) case 1; (b)case 2

Temperature distribution on each wall surface

Temperature distribution on each wall surface in each case is shown in table 2. In case 2, the surface temperature on the walls was shown to be about 1℃ higher than in case 1. The surrounding walls in case 1 were considered to receive a large radiation heat transfer from the human model.

Mean radiant temperature and operative temperature

In case 1, the mean radiant temperature was about 23.2℃, was lower than in case 2. This corresponded with the fact that, in case 1 the temperature was 0.5℃ lower than that in case 2. And in case 1, the operative temperature was lower than that in case 2, where only airflow cooling was used. The radiant floor cooling surface, therefore, showed good cooling efficiency.

Table 2 mean wall temperature [℃]

case	floor surface	east wall	west wall	south wall	north wall	ceiling
1	21.5	23.2	23.3	23.5	23.4	24.5
2	22.6	24	24.5	24	23.0	25

CONCLUSIONS

(1) The radiant floor cooling system can remove the heat by radiation and convection. The hybrid system composed of radiant floor cooling and displacement ventilation can provide higher thermal comfort degree comparing with the all-air conditioning system.

(2) For the same amount of cooling load, the radiant floor cooling system combined with displacement system kept the mean radiant temperature and operative temperature lower than all-air conditioning system, and therefore had better cooling efficiency than the all-air system.

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