Experimental Study of the Floor Radiant Cooling System Combined with Displacement Ventilation

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Abstract: As a comfortable and energy-efficient air conditioning system, the application of floor radiant heating system is used increasingly greatly in the north of China. As a result, the feasibility of floor radiant cooling has gained more attention.

To examine the thermodynamic performance of the floor radiant cooling system, we measured the operational conditions including the minimum floor surface temperature, the cooling capacity, and the indoor temperature field distribution under different outdoor temperatures in Beijing. Because the ground temperature changes with the mean temperature of the supplied and returned water and room temperature, the mean temperature of the supplied and retuned water was obtained. Finally, we analyzed the phenomenon of dewing and developed measures for preventing it. The dry air layer near the floor formed by a displacement ventilation system can effectively prevent dews on the surface of the floor in the wet and hot days in summer. In addition, for the sake of the displacement ventilation system, the heat transfer effect between floor and space is enhanced.

Our analysis pointed out that floor radiant cooling system combined with displacement ventilation ensures good comfort and energy efficiency.

Key words: floor radiant cooling, displacement ventilation, dewing

1. INTRODUCTION

In north of China radiant floor systems are widely used to heat buildings, but very few systems [1]are also used for cooling purposes. Reasons such as cooling capacity, comfort factors and risk of condensation of floor surface have made people worry about the efficiency of floor cooling system. The convective heat exchange coefficient for floor cooling is much lower than for floor heating. There are also several comfort factors, such as acceptable floor temperature, vertical air temperature difference and dew-point temperature, that may reduce the cooling capacity of a floor system.

This paper discussed the mechanism of heat transfer and thermal calculation of floor cooling system, the temperature distributing such as floor surface, wall surfaces, ceiling and indoor air was tested under different conditions.

2. THEORY

The lower temperature floor surface exchanges heat with other surfaces and space air by ways of convective and radiant. The total heat flux between floor surface and space can be considered as the sum of the convective and radiant heat transfer:

$$q_{tot} = q_c + q_r \qquad (1)$$

Where

q_{tot} = total heat transfer (W/㎡),

q_c = convective heat transfer (W/㎡),

q_r = radiant heat transfer (W/㎡).

Normally radiant grey surfaces are assumed, the radiant heat flux between the floor surface and other surfaces can be written

$$q_r = \frac{\sigma\left(T_{mrt}^4 - T_f^4\right)/F_1}{\frac{1-\varepsilon_1}{\varepsilon_1 F_1} + \frac{1}{F_1\varphi_{1,2\to 6}} + \frac{1-\varepsilon_{2\to 6}}{\varepsilon_{2\to 6}F_{2\to 6}}} \qquad (2)$$

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Where

$F_{2\to6}$ = area of other surfaces（㎡),

$\varepsilon_{2\to6}$ = mean emittance of the other surfaces,

σ = Stefan-Boltzmann constant (5.67×10^{-8}［W/(㎡K^4)］),

T_f = absolute temperature of floor surface (K),

F_1 = area of floor surface（㎡),

ε_1 = area of floor surface（㎡),

$\varphi_{1,2\to6}$ = view factor between floor surface and other surfaces,

T_{mrt} = mean radiant temperature (K),

$$T_{mrt}=\sum_{i=2}^{6}T_i\frac{F_i}{\sum_{i=2}^{6}F_i}, \quad (3)$$

Since the emittance for grey surfaces, as in the case of internal wall surfaces in a room, are nearly equal (between 0.9 and 0.95), it is approximated 0.95. $\varphi_{1,2\to6}$=1.

Because there was insulation under the pipe and surround walls, the heat loss can be assumed zero. Thus

$$q_{tot}= c_w V (T_s - T_r) \quad (4)$$

Where

c_w = specific heat of water (J/ (m^3 K)),

V = water flow rate (m^3/s),

T_s = supply water temperature (K),

T_r = return water temperature (K),

The convective heat exchange is then calculated from Equation 1 as

$$q_c = q_{tot} - q_r \quad (5)$$

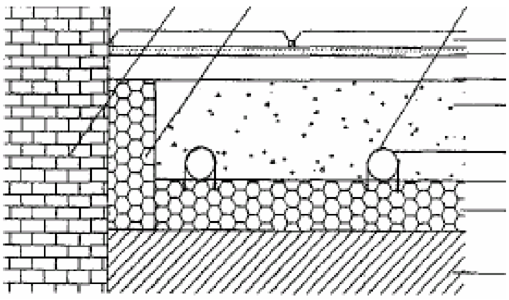
The two main parameters for providing acceptable thermal conditions in a space, which may be significantly influenced by the heating/cooling system, are the air temperature and the mean radiant temperature. The combined influence of these two temperature is expressed as the operative temperature. For low air velocities (< 0.2 m/s), the operative temperature can be approximated with the simple average of air and mean radiant temperature. This mean that the air temperature and the mean radiant temperature are equally important for the level of thermal comfort in a space. If the floor surface temperature is decreased by 5 ℃ and all other surfaces temperatures are assumed to be unchanged, then the mean radiant temperature will decreased by 2 ℃. The impact on an occupant is expressed by the operative temperature, which will decrease by 1℃. Put another way , a floor surface temperature that is 5℃ lower will have the same cooling effect as lowering the air temperature by 2℃. A cooled floor will also exchange heat with the air by convection and by radiant with the surrounding surfaces and in this way will also further decrease the mean radiant temperature and the air temperature.

Contrast to ceiling radiant cooling system, the convective heat exchange coefficient between the cool surface and the space air is lower. But for a radiant cooling system, an important factor is the angle factor between the occupants and the radiant heat source. This factor depends on the distance a person and the surface and area of the surface. A floor normally has the highest angle factor to the occupant of all surfaces (walls, ceiling, windows, etc.) in a space.

For a person positioned at the center of a 6 m by 6 m floor, the angle factor is 0.40 for a sedentary person and 0.37 for a standing person. For a 12 m by 12 m floor, the corresponding angle factors are 0.46 for a sedentary person and 0.43 for a standing person. This should be put in relation to the angle factor for a half-room, 0.5. If the floor surface temperature is decreased by 5℃ and all other surface temperatures are assumed to be unchanged, then the mean radiant temperature will decrease by 2 ℃.

3. EXPERIMENT TESTS

The test room was in a institute of Beijing, with dimensions 6.4×5×2.9m. Insulation was paved under the pipe, and surrounding the walls. See figure 1.



In experimental test, we emphases the system

Fig.1 typical floor system

of floor radiant cooling system combined with displacement ventilation. Experiment were performed under different ambient temperature, the results see table 1 and figure 2.

In August 7th, 2004, ambient temperature vary from 27℃ to 31.5 ℃. The relative humidity outside was about 70%. After 17：00，The relative humidity of outside air higher than 70%. The equipment was operated from 8:30 AM. The temperature of supply water was 14℃， the return water was 7℃,. The water flow rate was 8L/s. The fan coil was not operated. The measured temperature of outdoor air, floor surface, other surfaces, and the temperature field in the space is shown in table 1 and figure2.

Tab. 1 measured surface and air temperature

Measured point / time	floor	East wall	South wall	West wall	North wall	ceiling	0.1	1.1	1.7	2.2
9:00	27.3	25.9	27.3	27.2	26.7	26.8	25.6	26.0	26.8	27.0
10:00	27.2	25.8	27.2	27.2	27.2	26.9	25.4	26.1	26.9	27.2
11:00	26.9	25.6	26.9	27.0	27.4	26.8	24.7	25.9	26.7	27.0
12:00	27.0	25.8	27.1	27.2	27.6	26.9	24.4	26.0	26.6	27.1
13:00	27.2	25.7	27.0	26.8	27.7	26.9	23.9	25.4	26.3	26.5
14:00	27.0	25.3	27.2	26.9	27.7	26.8	23.8	25.5	26.3	26.5
15:00	26.5	25.3	26.8	26.7	27.7	26.8	23.6	25.4	26.1	26.5
16:00	26.3	25.4	27.0	26.6	27.5	26.7	23.3	25.4	26.2	26.6
17:00	26.4	25.1	26.6	26.6	27.8	26.8	23.8	25.3	26.1	26.5
18:00	26.5	25.3	26.5	26.5	27.8	26.7	23.6	25.2	26.0	26.4

In addition, before the system was operated, the air temperature at point 1.1m in space was 26.0℃ and relative humidity was 58.4%. After the system operated 4 hours, the temperature at point 1.1m was 25.2℃, and relative humidity was 75.2%. At point of 0.01m, the temperature of the air layer near the floor was 23.3℃, and relative humidity was 78.1%. Thus the dew point near the cool floor was 19.2℃.

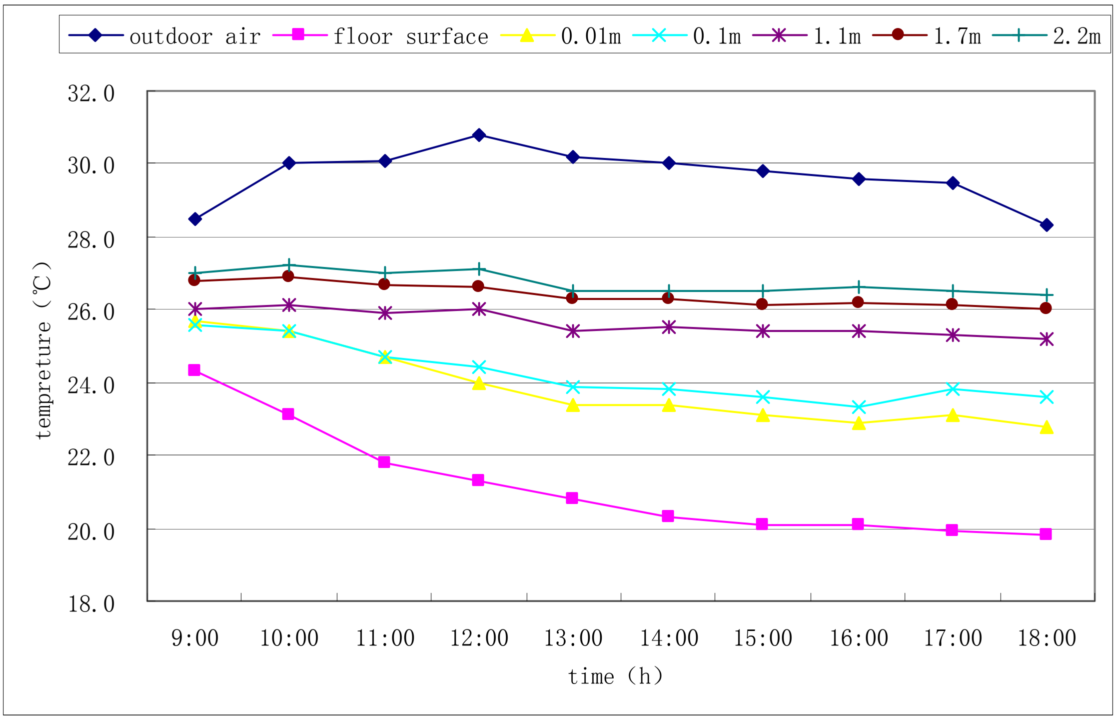


Fig.2 Temperature field in the room

From figure 2, we can see that when the temperature of outdoor air is not too high and the relative humidity was relative higher, the floor radiant system alone can provide enough cool capacity to maintain the temperature, but relative humidity was too high to make people feel comfort for activity level in space. We opened fan coil to dehumidify the space air at 18:00 AM. The temperature of supply water to fan coil was set to 6 . After 15 minutes, the relative humidity decreased 20%, was about 55%. Occupants felt comfort in the space. Then we turned off the fan coil. We can draw a conclusion that the radiant floor cooling system combined with displacement ventilation can ensure good comfort in muggy day.

4. CONCLUSIONS

1 A floor cooling system should primarily be used where the system also will be used for heating in winter.

2 It is possible to cool with a floor system but, due to the limited cooling capacity, the room temperature may not always be effectively controlled.

3 The air temperature difference between ankles (0.1m level) and head (1.1m level) is less than 3 K for sedentary persons.

4 The use of dehumidification in a room by an air-conditioning system will decrease the dew-point temperature and then increase the cooling capacity of a floor system.

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