Experimental Study On Operating Characteristic For Combined Radiant Floor And Fan Coil Cooling System In Under Low Temperature And High Humidity

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Abstract. The combined radiant floor and fan coil cooling (RFCAFC) system is widely used due to its high comfort and large energy saving potential. In this study, as an example, the combined RFCAFC system was studied in a high humidity environment in Jinan, Shandong Province, China. Days with similar outdoor meteorological conditions were grouped, and the comfort level and other evaluation indicators. The RFCAFC had good energy efficiency and comfort when the room was in a high humidity environment. This study showed that the radiant floor surface temperature uniformity coefficient (S) fluctuated between 0.7 and 1.0. The proportion of the total cooling capacity contributed by fan coil cooling under low temperature and high humidity (LH) is 68.0%. The combined cooling system used the LH operating strategy, the PMV value fluctuated from 0.12 to 0.49. Based on this study, the following recommendations for the combined cooling system can be made: (1) When the outdoor humidity is high, the radiant floor system should be turned on early to provide cooling capacity. (2) The operation strategy of the combined cooling system must be able to respond in real time to changes in outdoor meteorological conditions to prevent discomfort in times of extreme heat or humidity.

1 Introduction

It is well known that energy consumed by buildings accounts for more than 40% all global energy consumption, and 60% of that goes to ensuring indoor thermal comfort for occupants [1, 2]. Over the years, many studies have investigated energy consumption by radiant cooling systems and found that, compared to conventional convection air conditioning systems, radiant cooling systems can reduce energy consumption by about 40% [3-5].

Radiant floor cooling (RFC) has attracted widespread attention because of its good thermal comfort, low energy consumption, building space saving, and low operating noise. Researchers have conducted many practical application studies and field measurement studies on radiant floor air conditioning systems [6, 7]. Sourbron et al. compared the response times of RFC and convection air conditioning systems based on the thermal inertia of the envelope and proposed an operational strategy utilizing intermittent operation [6, 8-10]. Romaní et al. proposed a water supply temperature operation strategy where the water supply temperature is continuously adjusted according to the outdoor temperature, but this strategy was more complicated than others. A water supply temperature operating strategy is well adapted to maintaining stable operation while accounting for uncertainties resulting from increased indoor heat loads or solar radiant heat gain throughout the day. However, RFC system is not able to immediately deal with changes in hot and cold loads due to the high thermal inertia of buildings, so other energy handling systems must be set up to buffer rapid change [11-15].

Currently, RFC system is not widely used in residential buildings and small offices without central air conditioning because of the high risk of condensation, slow response time, difficulty in controlling multiple zones, and insufficient floor cooling capacity due to intermittent use within high humidity environments. Based on the above problems, we built a RFCAFC automatic operation system and analyzed the operating characteristic of on building energy consumption and thermal comfort under low temperature and high humidity. This study provides a strong reference and basis for further study of the operating characteristics of combined systems under high humidity environments and for further promotion of the combined system in small scale residential applications.

2 Experimental descriptions

2.1 Introduction of the laboratory

The experimental laboratory was located in Jinan, China, which is in a hot summer and cold winter climate zone. The enclosed structure adopted aerated concrete
integrated composite wall panels, which have low thermal conductivity and good thermal stability. The laboratory was a single building with length, width, and height of 4.00 m, 2.80 m, and 3.00 m, respectively, and a total construction area of 11.2 m². The exterior walls were all 250 mm aerated concrete integrated composite wall panels. The floor plan of the laboratory and building is shown in Figure 1.

Fig. 1. Photographs of the floor plan and experimental building

The radiant floor coil adopted the double circuit dry buried pipe arrangement. The floor radiant coil pipe diameter was 12 mm, the pipe wall thickness was 2 mm, the coil spacing was 60 mm, and the pipe was PE-RT pipe. The radiant floor surface decoration material for the tile surface and radiant floor structure is shown in Figure 2. Indoor temperature sensors, humidity sensors, and anemometers were installed to measure indoor temperature, humidity; the measurement points were arranged as shown in Figure 3.

Fig. 2. Radiant floor structure

Fig. 3. Location of the indoor measuring points

In figure 3, W is the wall surface measurement point, S is the ground measurement point, O is ground center.

2.2 Introduction of the combined cooling system

The operating principle of the RFCAFC system is shown in Figure 4. The RFCAFC system consisted of a cold source, a constant temperature water tank, a primary distribution system, a secondary distribution system (mixer pump), a safety component, and an air conditioning terminal. The detailed parameters of the experimental equipment are shown in Table 1.

Fig. 4. Schematic of the cooling system

| Paramet ers                  | Instruments                      | Range       | Accuracy | Sample frequency |
|------------------------------|----------------------------------|-------------|----------|------------------|
| Room air temperature         | Temperature and humidity meter   | 20~80°C     | ±0.5°C   | 30 s             |
| Room air relative humidity   | Temperature and humidity meter   | 0%~100%     | ±3%      | 30 s             |
| Floor surface temperature    | PT100-type thermometer          | -100~30°C   | ±0.5°C   | 2 s              |
| Wall and ceiling temperature | PT100-type thermometer          | -100~30°C   | ±0.5°C   | 2 s              |
| Water temperature            | PT100-type thermometer          | -40~125°C   | ±0.5°C   | 2 s              |
| Water flow rate              | Flow meter                       | 0~3 m³/h    | ±0.5%    | 2 s              |

3 Experimental cases and evaluation indices
3.1 Experimental cases

These experiments were conducted in August and September, which are representative of the summer cooling season in Jinan, China. The outdoor temperature varied from 26°C–40°C and the outdoor humidity varied from 35%–94% during the test period, as shown in Figure 5.

![Fig. 5. Meteorological conditions during the experiment, (a) outdoor air temperature, (b) outdoor air relative humidity, and (c) solar radiation.](image)

When the outdoor temperature and humidity ranges were 21°C–29°C and 74%–94%, respectively, the condition was referred to as low temperature and high humidity (LH). The environmental condition was defined as shown in Table 2.

| Experiment time | Temperature and humidity characteristics | Temperature range (°C) | Humidity range (%) |
|-----------------|------------------------------------------|------------------------|-------------------|
| 2021.8.20       | LH                                       | 21 – 29                | 74 – 94           |
| 2021.8.22       |                                          |                        |                   |

3.2 Evaluation indices

3.2.1 Radiant floor surface uniformity temperature coefficient (S)

The average temperature of the surface of the radiant floor directly affects the heat exchange at the surface of radiant floor, this study used the S value to express the cooling capacity of the radiant floor. The closer the average temperature of the radiant floor surface to the lowest temperature of the radiant floor surface, the closer S is to 1.

\[
S = \frac{T_{s,\text{max}} - T_{s,\text{min}}}{T_h - T_g}
\]  

(1)

where: \(T_{s,\text{max}}\) is the maximum radiant floor surface temperature, °C; \(T_{s,\text{min}}\) is the minimum radiant floor surface temperature, °C; \(T_g\) is the radiant floor water supply temperature, °C; and \(T_h\) is the radiant floor return water temperature, °C.

3.2.2 Thermal comfort

The international standard ISO7730 uses the Predicted Mean Vote (PMV) and Predicted Percentage Dissatisfaction (PPD) to describe and assess the comfort of an indoor thermal environment.

3.2.3 System cooling capacity

The cooling capacity and operation status of the combined cooling system was evaluated by calculating the heat load carried at different air conditioning terminals. The operation of the combined cooling system at each stage of the day was analyzed based on the heat load capacities of different system components. The cooling capacity of the RFCAFC system can be calculated according to equation (2) and (3).

\[
Q_R = c_p m (T_h - T_g)
\]

(2)

\[
Q_F = G_n (h_2 - h_1)
\]

(3)

where: \(Q_R\) is the RFC capacity, W; \(Q_F\) is the fan coil cooling capacity, W; \(c_p\) is the specific heat at constant pressure, J/(kg·°C); \(m\) is the mass flow rate per unit area of circulating duct, kg/s; \(G_n\) is the fan coil air supply volume, kg/s; \(h_2\) is the return air outlet enthalpy, kJ/(kg·k); and \(h_1\) is the enthalpy at the supply air outlet, kJ/(kg·k).

4 Results

4.1 Radiant floor surface temperature

The changes in radiation floor surface temperature under different operating strategies are shown in Figure 6. The black curve indicates the change trend of S and the red line indicates the fluctuation range of S. Under the LH operating strategy, S remained basically stable at about 1.0, which was a desirable level.

![Fig. 6. S range for the LH.](image)

4.2 Thermal comfort

Figure 7 plots the PMV values over time for the different operation strategies. It can be seen that when the combined cooling system used the LH operating strategy, the PMV value fluctuated from 0.12 to 0.49,
with the average value of 0.31. Due to the higher amount of solar radiation reaching the room through the south window, the combined cooling system was unable to completely eliminate the indoor heat load, which finally led to a certain reduction in indoor comfort from 13:00 to 15:00. Therefore, to improve thermal comfort, it is necessary to adjust the operation strategy of the combined cooling system in real time according to the changes in outdoor meteorological conditions.

Fig. 7. Thermal comfort under the LH.

4.3 System cooling capacity

Figure 8 shows the change in cooling capacity of the combined cooling system over time under outdoor meteorological conditions. According to the figure, in the initially high humidity environment, the fan coil accounted for about 68.0% of the total cooling load under the LH operating strategy. We see that during the LH operating strategy were fan coil system and floor radiation system turned on simultaneously to dehumidify and cool due to the high outdoor humidity. So, when the outdoor humidity is high, the radiant floor system should be turned on early to provide cooling capacity.

Fig. 8. Cooling loads taken on by radiant floor and fan coil under the LH.

5 Conclusion

In this study, a RFCAFC system for a single building was established and tested. The effects of operation strategies on radiant floor surface uniformity temperature coefficient, the thermal comfort, and cooling capacity were analyzed. The conclusions of the study are as follows.

(1) Under the LH operating strategy, $S$ remained basically stable at about 1.0, which was a desirable level.

(2) It can be seen that when the combined cooling system used the LH operating strategy, the PMV value fluctuated from 0.12 to 0.49, with the average value of 0.31. It is necessary to adjust the operation strategy of the combined cooling system in real time according to the changes in outdoor meteorological conditions.

(3) In the initially high humidity environment, the fan coil accounted for about 68.0% of the total cooling load under the LH operating strategy. When the outdoor humidity is high, the radiant floor system should be turned on early to provide cooling capacity. The acknowledgements should be typed in 9-point Times, without title.

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