Analysis of Indoor Thermal Comfort of Different Air-conditioning Systems

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Abstract. Taking a typical two-person office as the research object, the indoor thermal comfort of the radiant cooling-displacement ventilation air-conditioning, the radiant cooling-personalized air-supply air-conditioning, and the all-air air-conditioning were simulated and studied, and the indoor thermal comfort index properties was analyzed. It was found that the indoor personnel activity area with radiant cooling-personalized air-conditioning had the lowest air supply temperature, PMV and PPD, and the air supply speed met the requirements. The thermal comfort effect of the human body is significantly better than that of the other two air-conditioning, which provides a reference for the design, promotion and application of the new air-conditioning of radiant cooling and personalized air supply combined cooling in actual projects.

1. Introduction
Energy saving is an extremely urgent task for our country. Air-conditioning energy consumption accounts for more than half of the energy consumption of the entire building. Radiant cooling has the advantages of energy saving, strong comfort and low pollution, and has good application prospects [1]. Radiant cooling refers to the technical method of reducing the temperature of one or more surfaces of the inner surface of the enclosure structure to form a cold radiating surface, which relies on the radiant heat exchange between the radiating surface and the human body, furniture and other surfaces of the enclosure structure to cool down. Since the share of radiant heat transfer in the radiant cooling system is more than 50%, when the radiant cooling is used, the indoor operating temperature can be reduced by 1~2°C compared with the traditional air conditioning system [2]. However, the cooling capacity of the radiant cooling system is limited, and it cannot bear the indoor wet load, and the surface of the radiant panel is also prone to condensation. These shortcomings restrict the promotion of radiant cooling technology [3]. Personalized air supply is to send a small amount of clean air to the vicinity of the human body, which is a way of air supply that pays attention to personal control of the thermal environment. Combining personalized air supply and floor radiation effectively, as a new air conditioning system, it can not only avoid condensation on the radiant panel, but also reduce the air supply volume of the air conditioning system, thereby reducing the energy consumption of the air conditioning system [4].

In the study, the numerical models of three different working conditions are established, such as the indoor radiant cooling-displacement ventilation air-conditioning, radiant cooling-personalized air-supply air-conditioning and all-air air-conditioning. Under the circumstance of the three working conditions, the influence of indoor human thermal environment comfort is then investigated by adopting some standards, such as the temperature and flow rate of air supply, PMV and PPD [5].
2. Mathematical model

2.1. physical model

The research object is a typical two-person office. The size of the room is 5m×4m×3m, and the north wall is set as the outer wall. The north wall has a glass window, the size is 1.8m×1.8m; the rest of the walls are inner walls. The specific equipment components are shown in Table 1. Working condition 1 is set as a radiant cooling-displacement ventilation and air conditioning system, working condition 2 is set as a radiant cooling-personalized air supply air conditioning system, and working condition 3 is set as a full-air air conditioning. The numerical models of the three working conditions are shown in Figure 1.

Table 1. Office internal components size and quantity.

| Name               | Size(m)         | Quantity |
|--------------------|-----------------|----------|
| human body         | 0.4 × 0.3 × 1.2 | 2        |
| desk               | 1.2×0.8×0.6     | 2        |
| lamp               | 1.2×0.3×0.3     | 3        |
| computer           | 0.5×0.4×0.4     | 2        |
| Air outlet         | 0.4×0.4         | 1        |
| Air inlet          | Variety         | 1        |
| Personalized tuyere| Variety         | 1        |

![Figure 1](image)

(a) Working condition 1  (b) Working condition 2  (c) Working condition 3
1-Air inlet, 2-lamp, 3-Air outlet, 4-Radiant floor, 5-North window, 6-computer, 7-desk, 8-Personalized tuyere

Figure 1. Three types of air-conditioning mode office interior equipment layout diagram

2.2. Model simplification and assumptions

In order to facilitate the study, the following assumptions are made for the model: (1) The indoor air is regarded as an incompressible Newtonian fluid, and the fluid flows in a steady state, ignoring the heat dissipation caused by the viscous force of the fluid; (2) The interference of gas leakage will be ignored; (3) The atmospheric pressure is 101325Pa; (4) The Boussinesq model is used; (5) The indoor heat source is set as a stable surface heat source; (6) The radiant cold plate is one-way heat transfer (7) The internal wall temperature difference heat transfer is set to 2°C.

2.3. Simulation working condition setting

The office is a cyclical work place, and the planned personalized air supply volume accounts for 30% of the total air volume, the radiation temperature is set to 20°C, and the personalized air supply temperature is set to 19°C. The air supply parameters of the three working conditions are shown in Table 2.
2.4. Select model

2.4.1. Turbulence model
The speed of fresh air is high when it first enters the office, and when it reaches the ground, it enters the personnel activity area at a low speed. At this time, the thermal buoyancy generated by the indoor heat source becomes the main driving force for air flow. Therefore, indoor air flow mainly includes natural convection and forced convection. And mixed convection. This paper mainly studies the airflow phenomenon of personalized air supply in the personnel activity area, and chooses the RNG K-Ɛ two-equation turbulence model. This model has been successfully applied in the research of many scholars and can obtain more realistic and accurate simulation results.

2.4.2. Radiation model
As the main method of indoor cooling, the radiant cooling plate exchanges radiant heat with the inner surface of the indoor enclosure and internal heat sources such as the human body and computers. Therefore, the discrete coordinate radiation (DO) model can be selected to calculate the radiant heat more accurately.

| Working conditions | Radiation Temperature (°C) | Supply Temperature (°C) | Air volume (m³/s) | Velocity (m/s) | Tuyere size (m) |
|--------------------|---------------------------|-------------------------|-------------------|----------------|----------------|
| Background tuyere  |                           |                         |                   |                |                |
| 1                  | 20                        | 19                      | 77.523            | 1              | 0.15×0.15      |
| 2                  | ——                        | 710.097                 | 54.223            | 1              | 0.12×0.12      |
| 3                  | ——                        | 710.097                 | 23.3              | 0.5            | 0.08×0.08      |

3. Result and Discuss
The vertical temperature difference between the ankle and the head of the human body is in the international air quality standard ISO7730 when sitting in office (0.1m~1.1m) and in the American Society of Heating, Refrigeration and Air-Conditioning Engineering Standard ASHRAE5-92 when standing in office (0.1m~1.8 m) are not greater than the requirement of 3°C, and the personalized air conditioner mainly studies the surrounding environment of the human body, so the height of 0.1m from the front of the human body model is selected as 0.1 m, 0.4 m, 0.7 m, 1.1 m, 1.5 m, The arithmetic mean values of air temperature, speed, PMV, and PPD at the corresponding point of 1.8m are used as comparison objects to analyze the effects of the three working conditions on the thermal comfort of the human body.
3.1. Temperature analysis
It can be seen from Figure 2(a) that the overall temperature of Working Condition 2 is lower than the temperature under the other two working conditions. The temperature around the human body under the three working conditions gradually increases from the lower part of the room to the upper part of the room. The peak is at 1.1m from the floor, because this is the main area where personnel and office equipment form the heat load distribution. The temperature of working condition 2 is 0.91°C lower than working condition 1 on average, and 1.63°C lower than working condition 3 on average, because the personalized air supply is directly sent to the vicinity of the human body for cooling. All three working conditions meet the requirements. But the temperature of working condition 2 is lower, so working condition 2 meets the temperature requirements of the comfort of the personnel activity area more than other working conditions.

3.2. Velocity analysis
It can be seen from Figure 2(b) that the flow velocity of working condition 1 and working condition 2 increase with the increase of building height, but working condition 3 first decreases with the increase of building height, and then increases, but overall working condition 3 The speed is higher than other working conditions, because the air outlet of working condition 3 has the largest air supply volume, and the method of downward air supply is adopted. In addition to airflow diffusion and loss, there is also the obstructive effect of the table, which causes the wind speed to gradually decrease. At the height above the desktop, the wind speed increases with the height, because there are no airflow obstructions and the exhaust vent is set in the upper part of the room. Comparing working condition 2 and working condition 1, it can be found that under the premise of the same air supply volume and the same radiation temperature, the speed of working condition 2 is 0.11 m/s higher than that of working condition 1. This is because the personalized air supply is directly sent to near the human body, wind speed attenuation is less. In the three working conditions, the maximum speed value of the personnel activity area is less than 0.3m/s, which meets the wind speed requirements of the comfort air conditioner in the personnel activity area.
3.3. PMV and PPD analysis
The change rules of the two are basically similar, which conforms to the theoretical relationship between the two. In the three working conditions, the extreme value appears at 1.1m, which is affected by indoor personnel and equipment. The average PMV distribution and change trend in the area near the personnel is the same as the temperature value near the personnel. The closer the PMV value is to 0, the closer the PPD is to 0%, the more comfortable the human body feels, and the more reasonable the selected air supply conditions. Comparing the average values of PMV and PPD of working condition 2 and working condition 1, it is found that working condition 2 is 0.244 and 5.46 lower than working condition 1, PMV of working condition 2 is reduced by 35.78%, and PPD is reduced by 49.95%. Comparing the average values of PMV and PPD of condition 2 and condition 3, it is found that condition 2 is 0.954 and 36.21 lower than condition 3, PMV of condition 2 is reduced by 68.5%, and PPD is reduced by 76.8%. Although operating condition 2 also has some locations close to the heat source that do not meet the requirements of -0.5≤PMV≤0.5 and PPD≤10%, it is generally better than the other two operating conditions.

4. Conclusions
(1) Under the same design conditions, the average air supply temperature of the radiant cooling and personalized air-conditioning is 3.47% lower than that of the floor radiant-displacement ventilation air-conditioning system and 6.04% lower than the all-air air-conditioning system. The temperature gradient of the radiant cooling and personalized air supply air conditioning system meets the ISO7730 standard. When the personnel are sitting and standing, the temperature difference between 1.1m and 0.1m above the ground in the personnel activity area should not be greater than 3℃.

(2) Under the same design conditions, the maximum speed value of the personnel activity area of the three working conditions is less than 0.3m/s, which meets the wind speed requirements of the comfort air conditioner in the personnel activity area.

(3) Under the same design conditions, the average PMV around the human body of the radiant cooling and personalized air-conditioning system is reduced by 35.78% and 68.5%, respectively, compared with the other two cooling systems; the average PPD is reduced by 49.95% and 76.8%, respectively.

(4) The results show that the combined air-conditioning system with radiant cooling and personalized air supply can effectively improve the thermal comfort of indoor personnel. This new type of combined air-conditioning system has the value of promotion and research.

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