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Influence of asymmetric radiation on heat exchange of planar radiant air conditioning and its correction

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Abstract. In this paper, the influence of radiation asymmetry on radiant heat transfer in the room of plane radiant air-conditioning system is analyzed. The radiation heat transfer model used in the Fanger thermal comfort equation is introduced. Using Airpak simulation analysis, it is concluded that external Windows and external walls should be taken as separate enclosure structures to calculate the PMV value. A new radiation heat transfer model was established, and the radiation heat transfer was solved under the new radiation heat transfer model. As the radiation heat transfer in the PMV equation, the thermal comfort equation was modified.

1. Introduction

For plane radiation air conditioning, the main heat transfer mode between the human body and the environment is radiation heat transfer. The heat exchange only in the form of radiation accounts for more than 50 percent of the total heat exchange. And radiant board is impossibly even decorate each plane inside the room, because this can cause the radiation between different surface and human body to change quantity of heat to differ and cause asymmetry radiate, affect the thermal intimacy of human body. Therefore, it is necessary to study the influence of radiant heat transfer under asymmetric radiation, determine the radiant heat transfer of plane air conditioning under asymmetric radiation, and modify the thermal comfort equation based on asymmetric radiation.

2. Heat transfer model of Fanger thermal comfort equation and its applicability analysis

2.1 Heat transfer model of Fanger thermal comfort equation

When calculating the radiant heat transfer in the Fanger thermal comfort equation, the temperature of each surface of the room is regarded as the same temperature, and all the surfaces are regarded as the gray body surface. In the Fanger thermal comfort equation, both the human body and the room are simplified as spheres, and the simplified figure of the model is as follows:



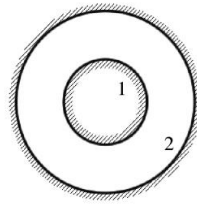


Figure 1. the simplified figure of the model

The formula for calculating the radiant heat loss between surface 1 and surface 2 in the figure can be expressed as follows:

$$\Phi_{1,2} = A_1 J_1 X_{1,2} - A_2 J_2 X_{2,1} \quad (1)$$

A_1 is the effective heat dissipation area, m^2 ; A_2 is the surface area of the envelope, m^2 ; J_1 is the effective human radiation, W/m^2 ; J_2 is the effective environmental radiation, W/m^2 ; $X_{1,2}$, $X_{2,1}$ are the angular coefficients of human body to environment surface and environment surface to human body, dimensionless respectively.

The calculation formula of effective radiation quantity is as follows:

$$J = \sigma T^4 - \left(\frac{1}{\varepsilon} - 1 \right) \frac{\Phi}{A} \quad (2)$$

According to the conservation of energy: $\Phi_{1,2} = -\Phi_{2,1}$.

$$J_1 = \sigma T_1^4 - \left(\frac{1}{\varepsilon_1} - 1 \right) \frac{\Phi_{1,2}}{A_1} \quad (3)$$

$$J_2 = \sigma T_2^4 - \left(\frac{1}{\varepsilon_2} - 1 \right) \frac{\Phi_{1,2}}{A_2} \quad (4)$$

In the formula, $\sigma = 5.67 \times 10^{-8} W/(m^2 \cdot K^4)$. T is the surface temperature, K ; ε is the surface emissivity, dimensionless. Φ for surface net radiation, when the outside heat transfer heat take positive, W . A is the surface area, m^2 ; T_1 is the rated temperature of human body surface. Generally, the outer surface temperature of human body clothing is taken as T_{cl} . T_2 is the ambient surface temperature, and the average ambient radiation temperature T_r is generally taken.

Concluded from the above formula, the radiant heat transfer is:

$$\Phi_{1,2} = \frac{A_1 \sigma (T_1^4 - T_2^4)}{\left(\frac{1}{\varepsilon_1} - 1 \right) + \frac{1}{X_{1,2}} + \frac{A_1}{A_2} \left(\frac{1}{\varepsilon_2} - 1 \right)} \quad (5)$$

$$R = \varepsilon_1 f_{cl} f_{eff} \sigma (T_1^4 - T_2^4) \quad (6)$$

2.2 Analysis of the applicability of the model

Firstly, the thermal comfort equation of the heat transfer model used for indoor a simplified palisade structure surface, simplifying the room to circular ignores the position of the room, and the size of the various surfaces of the room, to the surface as a gray body at the same time, ignore the inner surface of the wall emissivity on the form by radiation in the effect of radiation heat transfer. In the capillary plane radiation air conditioning room, the heat transfer between people and the indoor environment is mainly through the way of radiation heat transfer, the size of each surface area of the room, the temperature of the inner surface of the wall and the radiation rate of each surface will have a direct impact on the radiation heat transfer. Especially equipped with radiant panel wall in the face of the human body radiation heat transfer, due to the temperature difference between the temperature of the wall and other wall is large, radiation heat exchange between the human body is particularly strong, so neglect to the amount of radiation in computing will have very big effect, the form of heat by radiation will be difficult to determine.

Secondly, the model only considers the heat transfer between the wall and the human body, and the external window, which is an important part of the load calculation, is not taken into account. As the

heat transfer coefficient of the external window and the external wall is relatively large, the heat transfer between it and the outside world is relatively strong, which leads to a larger temperature difference between the temperature and the internal wall. Therefore, the radiation heat transfer between the external window and the human body is also considerable and cannot be ignored. Therefore, when the window is on the external wall, it needs to be calculated as a heat exchange surface alone. Therefore, in order to calculate the radiant heat exchange more accurately, the window on the outer wall should be used as a heat exchange surface alone.

3. Influence of asymmetric radiation heat transfer on thermal comfort equation

3.1 Establishment of asymmetric radiation room model

According to the above analysis, because of the size of the room, the surface temperature of each room and the emissivity of each surface of the room have a non-negligible influence on the radiation heat transfer, these factors must be taken into account when building the radiation model. The new room model was established as follows: the room was simplified as cuboids, the outer wall had Windows, the upper surface was a radiant roof, the lower surface was a floor, and the human body was simplified as a sphere with the same surface area as the human body. As shown in figure 2.1.

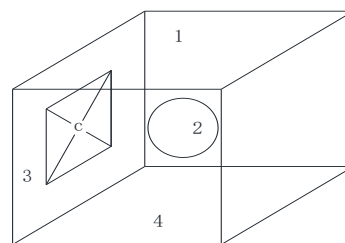


Figure 2. asymmetric radiation model

Some computational models of radiant heat transfer have been proposed in literature [1][2]. However, previous studies mainly focused on the cooling characteristics of radiant panels and the heating characteristics of radiant panels. The research content was limited to the radiation heat transfer between the surface of the maintenance structure, and the human body was not taken as part of the radiation model. Literature [3] proposed to take the human body as part of the model, but the human body was not taken as part of the radiative heat transfer system when calculating the radiative heat transfer. Due to thermal comfort equation used in the radiation model, on the surface of each part of the human body is simplified as the same gray body surface emissivity, inside the room was simplified as the surface emissivity of the same gray body, and in the roof of radiation cooling or heating system, the radiation temperature of roof and floor and other walls of temperature difference value is bigger, so the calculation model are no longer two sphere model but more surface model, make it more surface closed system.

3.2 Solution of asymmetric radiation heat transfer model

The newly established radiative heat transfer model is a multi-surface closed system. The specific calculation process is shown as follows:

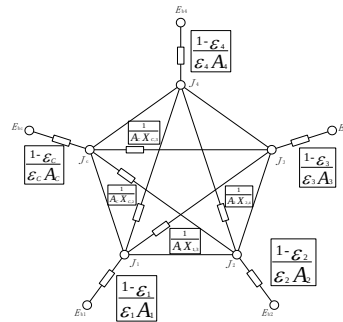


Figure 3. equivalent network diagram of asymmetric radiation heat transfer

$$J_i = \varepsilon_i \sigma T_i^4 + (1 - \varepsilon_i) \sum_{j=1}^c J_j X_{i,j}, \quad i=1, 2, 3, 4, c$$

(7)

The expression of net radiation quantity between the inner surfaces of two walls is:

$$\Phi_{i,j} = \frac{J_i - J_j}{\frac{1}{A_i X_{i,j}}}, \quad i, j=1, 2, 3, 4, c \quad (8)$$

The total net radiation heat transfer between the inner surface of each wall is:

$$\Phi_i = \sum_{j=1}^c \Phi_{i,j} = - \sum_{j=1}^c \Phi_{j,i} = \frac{E_{in} \cdot J_i}{\frac{1 \cdot \varepsilon_i}{\varepsilon_i A_i}}, \quad i=1,2,3,4, c \quad (9)$$

The formula of R for radiant heat transfer is:

$$R = \frac{\Phi_2}{A_D} = \frac{\varepsilon_2}{1 - \varepsilon_2} f_{cl} f_{eff} (\varepsilon_2 \sigma T_2^4 - J_2) \quad (10)$$

In the formula, J_2 is related to the surface emissivity of the interior wall interior surface and the Angle coefficient between the wall and indoor personnel. Therefore, the heat transfer R between the human body and the environment in the form of radiation becomes a function of the emissivity of the inner surface of the room wall and the Angle coefficient between the wall and the human body. The solving method of Angle coefficient of asymmetric radiation heat transfer model is shown in reference [4]

4. Airpak simulation and result analysis

4.1 Physical model

Airpark software was used to build an office room with dimensions of 3m 4m 5m. The window was 3m 1.6m. The lower edge of the window was 1.2m away from the floor surface. As shown in the figure below.

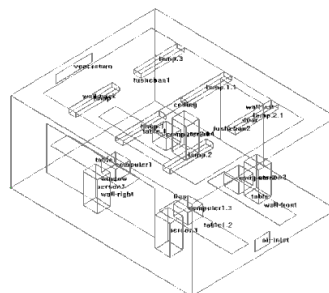


Figure 4. Airpark room model

4.2 analysis of simulation results

Case 1: the temperature of other enclosure structures except the radiant roof is regarded as the same temperature, and the average radiant temperature^[5] is adopted for calculation. The simulation results are shown in the following figures.

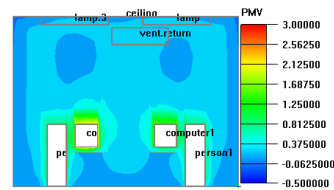


Figure 5. X=1.6 PMV value

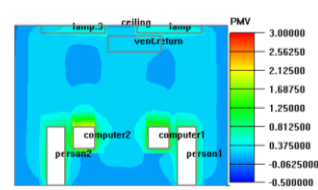


Figure 6. X=3.6 PMV value

Ceiling laying plus displacement ventilation is adopted, and the temperature of each wall surface is set as the average radiation temperature. PMV distribution cloud diagram is distributed symmetrically. PMV in the working area of human body is about 0.3, which is basically comfortable. The temperature near the computer is high due to the influence of heat source, and PMV value is high. FIG. 3.1 and FIG. 3.2 the distribution of PMV values is the same without considering the temperature differences among the surfaces of the envelope.

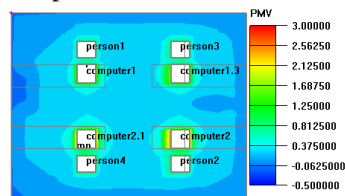


Figure 7. Y= 1.0pmv value

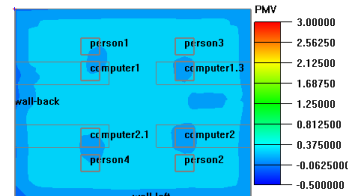


Figure 8. Y= 2.0pmv value

Ceiling laying plus displacement ventilation is adopted, and the temperature of each wall surface is set as the average radiation temperature. PMV distribution cloud diagram is symmetrically distributed. PMV in the working area of human body is about 0.3, which is basically comfortable.

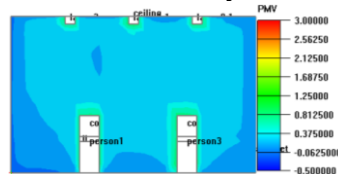


Figure 9. Z=-0.8 PMV

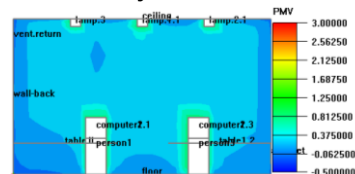


Figure 10. Z=-3.2 PMV

Ceiling laying plus displacement ventilation is adopted, and the temperature of each wall surface is set as the average radiation temperature. PMV distribution cloud diagram is symmetrically distributed. PMV in the working area of human body is about 0.3, which is basically comfortable. Fresh air flows into the floor at a temperature of about 26 degrees Celsius. PMV value is low and close to 0. As the temperature near the wall is close to 26 degrees Celsius, PMV value is close to 0. The PMV value gradually decreases from the periphery to the center until it approaches 0.

Case 2: consider the outer window as a separate heat transfer surface. The simulation results are shown in the following figures.

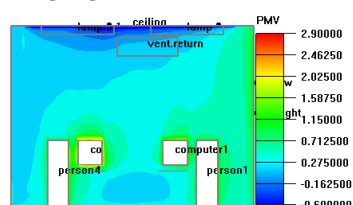


Figure 11. X=1.6 PMV value

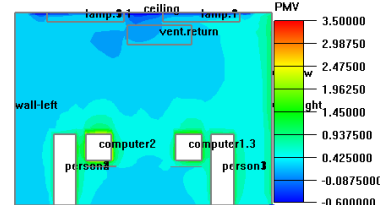


Figure 12. X=3.6 PMV value

The roof is laid with displacement ventilation, and the external window is considered as a separate heat exchange surface. Human body work area can be seen from the PMV map of PMV = 0.3 or so, basic comfortable, near computer PMV value is higher due to the influence of heat source temperature is higher, because the cooling effect of the airflow in radiation roof PMV value is low, PMV cloud distribution is symmetrical, no longer close to the window and wall part of the radiation effect is stronger, the body feel the slight fever, compared with figure 3.1 and figure 3.2, the PMV value is big, the body feels uncomfortable, away from the outside the window of a part of the PMV value reduced. The PMV

value distribution cloud diagram in figure 3.8 is the same as that in figure 3.7.

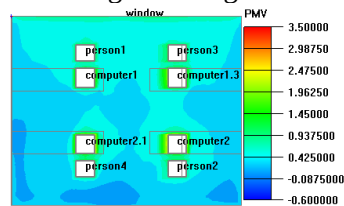


Figure 13. Y= 1.0pmv value

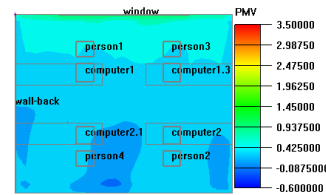


Figure 14. Y= 2.0pmv value

The roof is laid with displacement ventilation, and the external window is considered as a separate heat exchange surface. PMV distribution cloud can be seen that the human body work area PMV = 0.3, basic comfortable, near computer PMV value is higher due to the influence of heat source temperature is higher, because the cooling effect of the airflow in radiation roof PMV value is low, PMV cloud distribution is symmetrical, no longer close to the window and wall part because radiation effect is strong, the body feel the slight fever, compared with figure 3.3 and figure 3.4, the PMV value is big, the body feels uncomfortable, away from the outside the window of a part of the PMV value reduced. The PMV value distribution cloud diagram in figure 3.9 is basically the same as that in figure 3.10. As the screenshot in figure 4.10 is close to the radiant roof, the cooling temperature of the gas after the cooling effect of the radiant roof is lower than 0, but still within the human body comfort range.

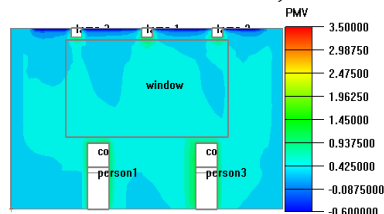


Figure 15. Z=-0.8 PMV value

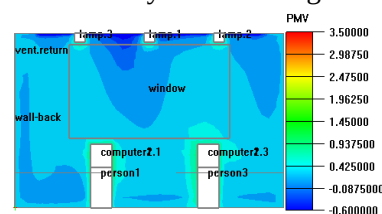


Figure 16. Z=-3.2 PMV value

The roof is laid with displacement ventilation, and the external window is considered as a separate heat exchange surface. PMV distribution cloud can be seen that the human body work area PMV = 0.3 or so, basic comfortable, near computer PMV value is higher due to the influence of heat source temperature is higher, because the cooling effect of the airflow in radiation roof PMV value is low, PMV cloud distribution is symmetrical, no longer close to the air supply outlet cross section of the whole PMV value closer to 0, got into the outlet cross section such as fresh air through the human body heat source heating temperature, PMV value between 0.3 to 0.6, the body feel slight fever.

5. Correction of thermal comfort equation based on asymmetric radiation heat transfer

Under the indoor thermal environment formed by radiation air-conditioning, human body not only dissipates heat by convection, radiation and evaporation, but also receives directional radiation from various surfaces, especially the cold/heat radiation surface, due to the asymmetric radiation field. The radiative heat transfer of human body surface facing radiation roof is relatively large due to the role of directional radiation, while other parts are relatively small. The heat transfer R between the human body and the environment in the form of radiation becomes the function of the emissivity of the inner surface of the room wall and the Angle coefficient between the wall and the human body.

In the thermal comfort equation when considering the influence of external window radiation and blackness of each radiant surface, the heat transfer of the radiative heat transfer part is:

$$R = \frac{\Phi_2}{A_D} = \frac{\varepsilon_2}{1 - \varepsilon_2} f_{cl} f_{eff} (\varepsilon_2 \sigma T_2^4 - J_2) \quad (11)$$

ε is the surface blackness of clothing, namely the clothing emissivity. Therefore, PMV equation derived from thermal comfort equation is also modified by the change of radiation heat transfer part.

6. conclusion

(1) The influence of the existence of radiation asymmetry in the room of the plane radiation air-

conditioning system on the radiation heat transfer is analyzed. This paper introduces the radiation heat transfer model used in the Fanger thermal comfort equation. The original radiation model does not take into account the existence of radiation asymmetry, including the emissivity of the inner surface of the room and the influence of the Angle coefficient between the surface and the human body, so it is not suitable for the evaluation of the thermal environment under the asymmetric radiation environment.

(2) The room model was established, and Airpak was used to simulate the PMV value distribution diagram in two cases. The 3d model of the air-conditioned room was established and divided into grids for calculation simulation. The average radiation temperature was calculated according to the set boundary conditions. The calculated average radiation temperature was used as the temperature of the enclosure structure. When the outer window is calculated as a separate enclosure structure and all surfaces are set according to the set boundary conditions, the area close to the outer window and the outer wall is no longer comfortable. Therefore, when calculating the PMV value, it is necessary to calculate the external Windows and outer walls as separate enclosure structures.

(3) Establish a new radiation heat transfer model, and solve the radiation heat transfer under the new radiation heat transfer model, and as the radiation heat transfer in the PMV equation, so as to modify the thermal comfort equation.

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