Indoor air distribution simulation of Perforated Ceiling Air Supply in summer

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Abstract. In this paper，the Airpak is used to modeling and numerical calculation traditional jet air supply and three conditions of perforated ceiling air supply，by contrast with the indoor temperature profile, velocity profile and PMV-PPD distribution,comprehensive analysis of indoor air distribution and thermal comfort.The results showed that：Compared with traditional jet air supply，perforated ceiling air supply with low speed and balanced ventilation might alleviate blowing sensation to indoor personnel，has a significant effect on the improvement of indoor air distribution and thermal comfort;Furthermore,The outlets of perforated ceiling air supply situate underpart of the room，cold air sent directly to the personnel working area，that can reduce supply air rate and guaranteeing the thermal comfort also， reduce the energy consumption of the air-conditioning system，has certain potential for energy conservation and emission reduction.

Keywords: Perforated ceiling air supply； numerical simulation； energy saving and emission reduction；thermal comfort.

1. Introduction

With the continuous improvement of people 's living environment thermal comfort requirements,and the positive response on energy conservation and emission reduction policies such as carbon neutralization and carbon peaking， such promotes the research and development of air conditioning field.At present， domestic and foreign scholars have done many studies on air distribution and energy saving measures in air-conditioning room.Article[1] simulated research on models under different airflow organization forms， concluded that different air distribution will affect the distribution of indoor temperature field and velocity field，thermal comfort and indoor air quality will have great differences also.Article[2] comparatively analyzed the temperature field, velocity field, temperature efficiency and human thermal comfort in the office with mixed ventilation and displacement ventilation，it showed the superiority of displacement ventilation in optimizing indoor air quality and saving energy consumption.Article[3]designed a new room air conditioner with 45 ° angle air supply，and simulated conventional air supply and new air supply ， the results showed that the temperature distribution uniformity is significantly improved and the thermal comfort is enhanced with new air supply， and it can reduce the air supply under the requirement of indoor temperature,achieve energy saving purposes.Article[4]simulated the air distribution and temperature field of the local perforated ceiling air supply under three different air volumes by CFD ， it showed that the air supply volume has obvious influence on the indoor flow field，it was easier to realize the fast switching of different temperature conditions in a large air flow，so as to realize rapid heating and cooling，but the relative noise is small, the temperature distribution is uniform, has certain comfort with small air volume。Article[5]modeled and numerically calculated the air-conditioning room with perforated ceiling air supply by CFD，it was found that the air supply volume, the height of the perforated plate, the porosity and the branch pipe all affect the indoor temperature field and velocity field distribution， and the best scheme of flow field uniformity was obtained.This paper with an objective of thermal comfort and energy saving， the

Airpak is used to modeling and numerical calculation traditional jet air supply and perforated ceiling air supply， and comparative analysis air supply modes bases on the technical indexes of indoor air quality (IAQ) such as indoor velocity field, temperature field and comfort in ISO7730 [6] standard， then optimization design the air outlet according to the contrast analysis results of three conditions of perforated ceiling air supply.

2. Numerical Simulation

2.1 Physical Model

This paper simulate an office in a teaching building.The office is located in the middle of the third floor,The length, width and height of the room are 5.0 m × 3.6 m × 3.8 m.The exterior wall faces south with a window of 2.0 m × 1.5 m,the other three sides are inner walls,the north wall is adjacent to the corridor, and the east and west inner walls are adjacent to the air-conditioned room.There is a staff, a computer, six fluorescent lamps in the room, other facilities include a work desk, a cupboard and an experimental bench.The air supply outlet is installed on the east wall,the traditional air outlet is downward and 75 ° to horizontal plane,perforated ceiling air supply is horizontally sent into the room through the supply outlet.The specific arrangement is shown in Figure 1.

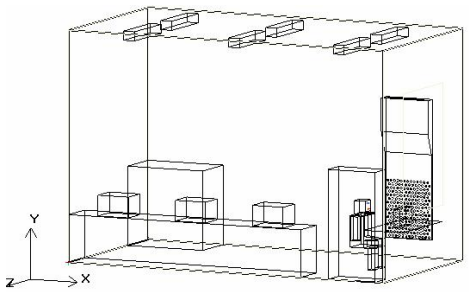


Fig.1 Physical model

2.2 The Governing Equation

The heat and moisture exchange process of indoor air meets the law of conservation of mass, momentum conservation and energy conservation.The main problem of this process is to solve the governing equation. General form of control equation is:

$$\text{div}(\rho U\varphi) = \text{div}(\Gamma_{\varphi}\text{grad}\varphi) + S_{\varphi} \quad (1)$$

In the formula,ρ is the air density; U is the velocity vector; φ is a general variable, which can represent fluid parameters such as velocity vector component and temperature； Γ_{φ} is the diffusion coefficient ； S_{φ} is the source term.The zero-equation turbulence model[8] proposed by Chen is used to solve the model,above model convenient application and reduces computing time.The finite volume method is used to discretize the governing equations in the computational domain,the difference scheme is mixed scheme,and the coupling method of pressure and velocity is SIMPLE algorithm.The convergence conditions are : the relative error of the flow equation is 1×10^{-3}, and the relative error of the energy equation is 1×10^{-6}.

2.3 The Boundary Condition

It is assumed that the indoor flow field in this paper is a three-dimensional, steady and incompressible turbulent model,the radiation between solid walls is not considered ,the heat conduction of external windows and external walls is one-dimensional steady-state,and other enclosure structures are adiabatic boundaries,ignore the influence of air leakage by door gap and window gap.In summer, the outdoor temperature is 33 °C, and the supply air temperature is 22 °C.

Tab.1 Boundary conditions of numerical simulation

Name	Quantity	Dimension	Model types	Boundary types	Parameter valu
East wall	1	5.0m×3.8m	Walls	Insulation	—
West wall	1	5.0m×3.8m	Walls	Insulation	—
South wa ll	1	3.6m×3.8m	Walls	Constant temperature	33℃
North wall	1	3.6m×3.8m	Walls	Insulation	—
Ceiling	1	5.0m×3.0m	Walls	Insulation	—
Floor	1	5.0m×3.6m	Walls	Insulation	—
South windo w	1	2.0m×1.5m	Walls	Constant temperature	33℃
Air outlet	1	—	Openings	—	22℃
Return opening	1	0.63m×0.15 m	Vents	Free flow	—

3. Results And Analysis

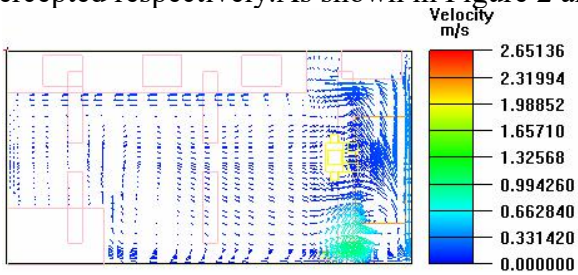
This paper studies the indoor airflow organization and the thermal comfort of perforated ceiling air supply,four working conditions are set up ,They are traditional jet air supply (condition-1) and three perforated ceiling air supply conditions ,the difference of condition-2 and condition-3 is the distance between air supply outlet and the ground.The air supply volume of condition-2 is different from condition-4,The specific working conditions are shown in Table 2 :

Tab.2 The working conditions

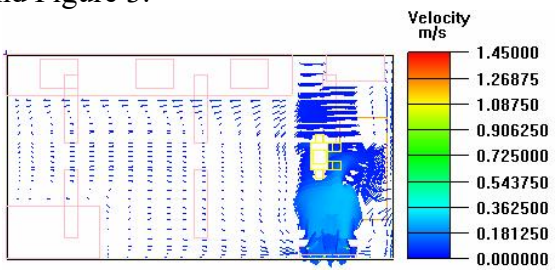
Conditions	Amount of outlets	Air supply volume （m^3/h）	Air supply velocity （m/s)	Distance between outl ets and ground （m）
Condition -1	1	330	2.65	2.3
Condition -2	56×40	330	1.45	0.3
Condition -3	56×40	330	1.45	0.15
Condition -4	56×40	230	1.0	0.3

3.1 Velocity Profile Analysis

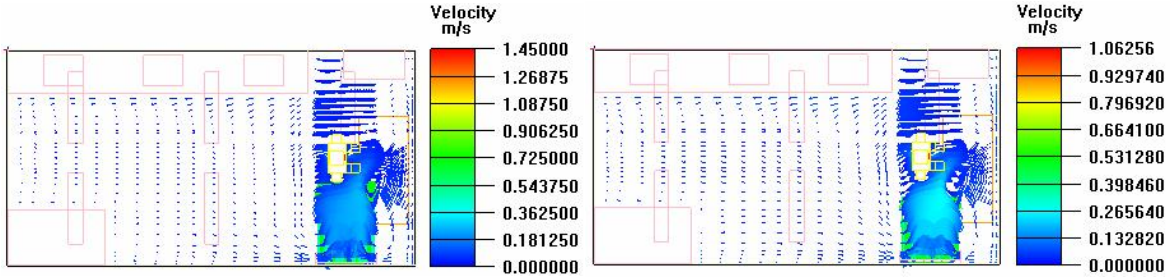
Taking the human activity area as the research object,analysis the influence of air supply outlet layout on indoor air distribution .The velocity profile of Y = 0.6m plane and Z = 1.8m plane are intercepted respectively.As shown in Figure 2 and Figure 3.



（a） Velocity profile of Y = 0.6m of Condition -1

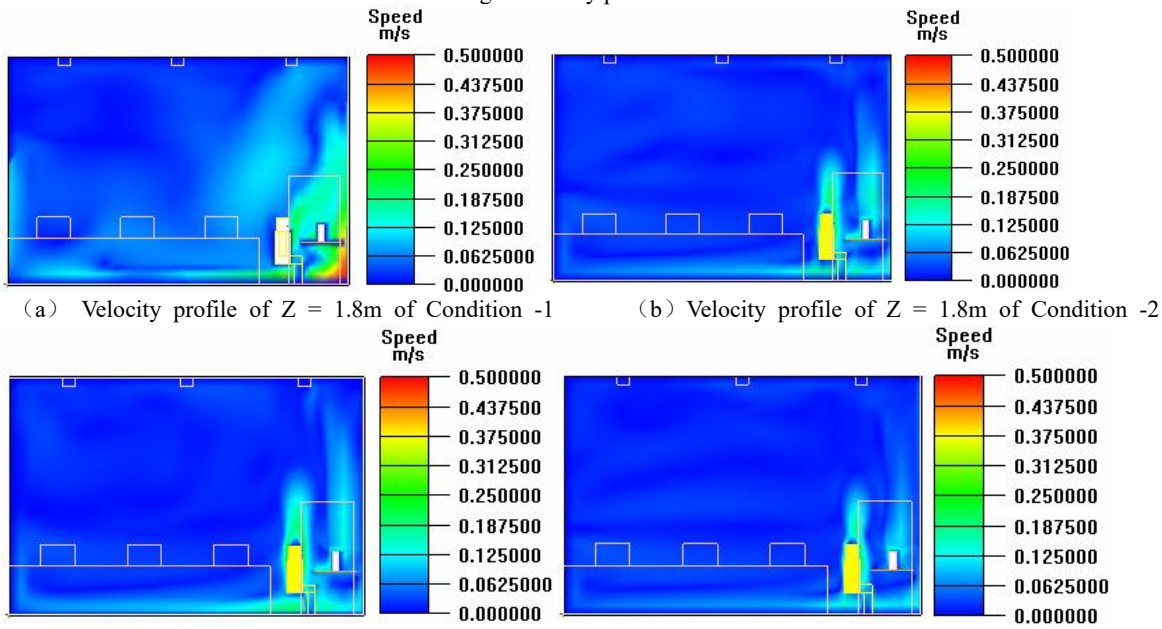


（b）Velocity profile of Y = 0.6m of Condition -2



（c） Velocity profile of Y = 0.6m of Condition -3 （d）Velocity profile of Y = 0.6m of Condition -4

Fig.2 Velocity profile of Y = 0.6m



（a） Velocity profile of Z = 1.8m of Condition -1 （b）Velocity profile of Z = 1.8m of Condition -2

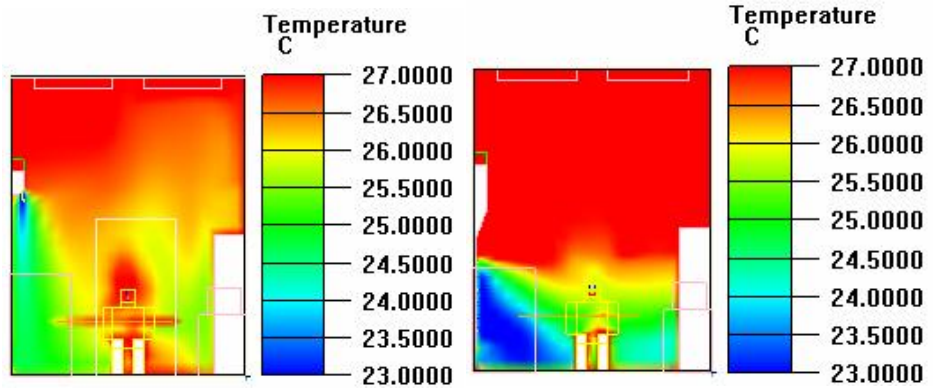
（c）Velocity profile of Z = 1.8m of Condition -3 （d）Velocity profile of Z = 1.8m of Condition -4

Fig.3 Velocity profile of Z = 1.8m

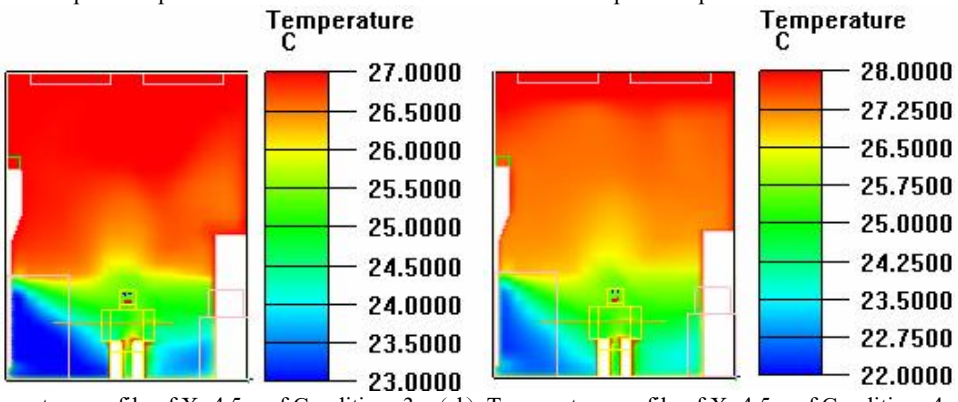
Compare (a)with (b),(c),(d)in Figure 2 and Figure 3,traditional jet air supply with high air supply velocity,the uniformity of airflow distribution in the personnel activity area is worse,and most of the Supply airflow to the ground directly wall-attached.The velocity decreases gradually in the process of mixing with the lower air, but the velocity around the knee is close to 0.5 m/s, which exceeds the requirement of the standard [9] that the indoor wind speed is not more than 0.3 m/s in summer,indoor personnel will have a sense of blowing.From (b),(c),(d)in Figure 2 and Figure 3,the distribution of indoor airflow is similar of three Perforated ceiling air supply Conditions,the horizontal supply airflow diffuses quickly, avoiding the air supply jet directly blowing the staff,the velocity distribution in the working area is uniform and the wind speed is small,the maximum wind speed around the personnel of Condition-2 is 0.15 m/s.Condition-3 reduces the installation height of air supply outlet， more cold air reaches the lower part of the room, so that the wind speed in the lower part of the room is slightly larger than Condition-2, and the maximum wind speed around the personnel is 0.17 m/s.In Condition-4, the air supply volume is reduced,then the air supply velocity decreases, and the air flow velocity in the room is less than that in Condition-2.It can be seen that the three conditions of Perforated ceiling air supply meet the requirements of wind speed in the standard.

3.2 Temperature Profile Analysis

The temperature profile of X = 4.5m plane and Z = 1.8m plane are intercepted respectively.As shown in Figure 4 and Figure 5.

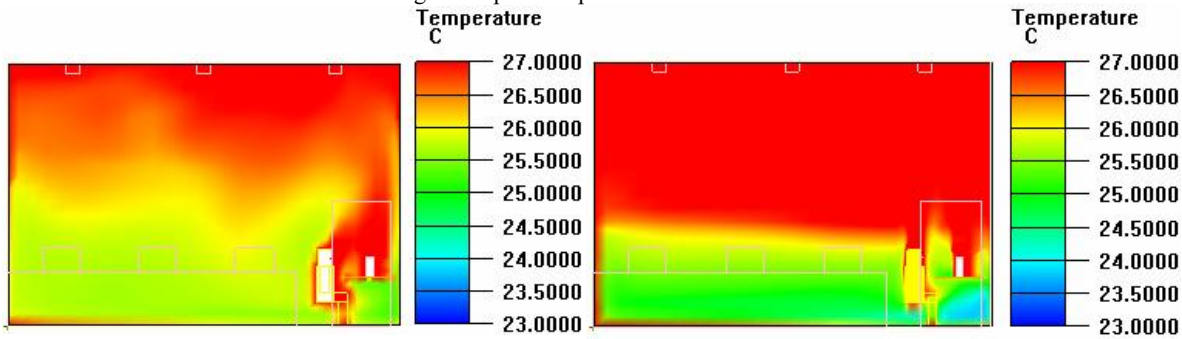


（a） Temperature profile of X=4.5m of Condition -1 （b）Temperature profile of X=4.5m of Condition -2

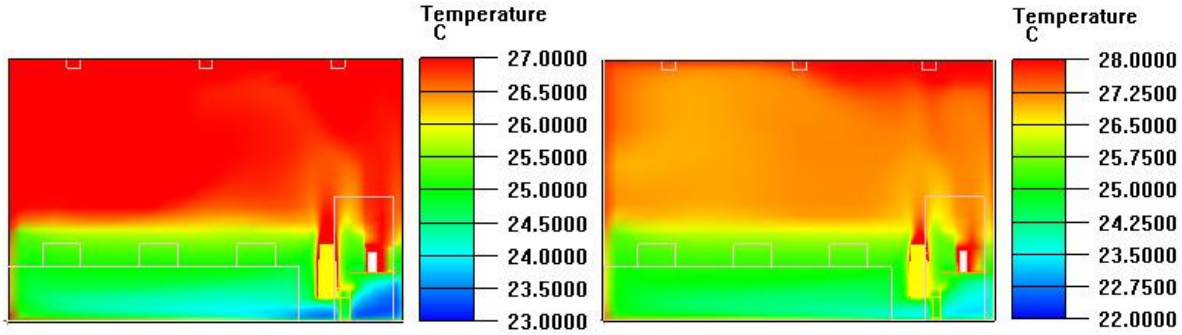


（c） Temperature profile of X=4.5m of Condition -3 （d）Temperature profile of X=4.5m of Condition -4

Fig.4 Temperature profile of X=4.5m



（a） Temperature profile of Z=1.8m of Condition -1 （b）Temperature profile of Z=1.8m of Condition -2



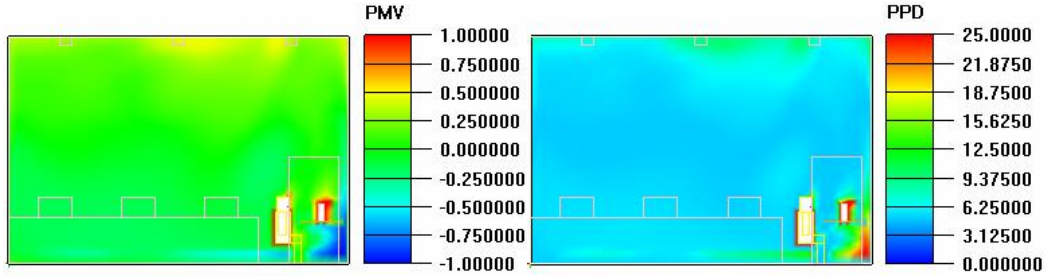
（c） Temperature profile of Z=1.8m of Condition -3 （d）Temperature profile of Z=1.8m of Condition -4

Fig.5 Temperature profile of Z=1.8m

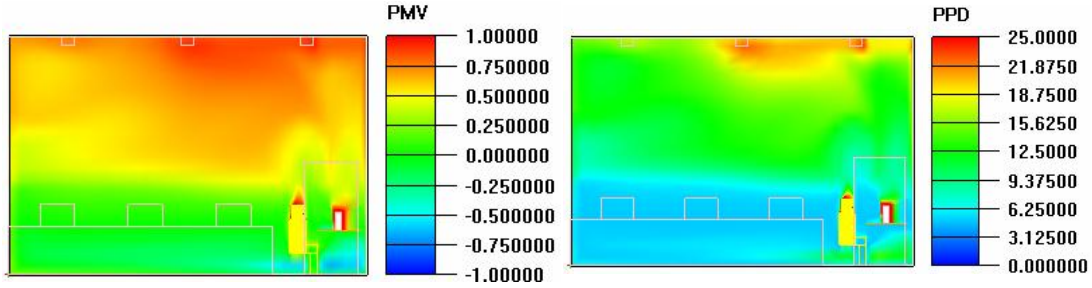
Compare (a) with (b),(c),(d)in Figure 4 and Figure 5.The outlet of traditional jet air supply situate upper part of the room， a part of the airflow is directly diffused to that area.Comparatively speaking， the temperature profile in the vertical direction is more uniform, but the amount of cold air reaching the working area is reduced， causing higher temperature in personnel working area， affect thermal comfort.On the other hand, the cold quantity is not fully utilized, resulting in a waste of energy.From(b),(c),(d)in Figure 4 and Figure 5， the temperature profile of indoor airflow is similar of three Perforated ceiling air supply conditions， the air supply jet directly acts on the

working area， there is temperature stratification in the vertical direction.Compare condition-3 to condition-2，more cold air is concentrated in the working area , so the temperature of working area is generally lower than that of condition-2, and less cold air in the upper part causing the temperature stratification in the vertical direction of condition-3 obvious.Compare condition-4 to condition-2， the reduction of cold air volume causes the overall increase of indoor temperature,it shows that the air supply volume has a significant effect on the indoor temperature.However, it can be seen from (d) in Figure 4 and Figure 5 that the temperature of the working area with small air volume is close to 26 ℃ , and the upper area is generally less than 28 ℃ ,which meets the requirements of thermal comfort level II in the standard [9].The comprehensive analysis shows that air supply jet directly acts on the working area with perforated ceiling air supply,avoiding the energy waste in the upper area.Furthermore,on the premise of meeting the comfort of personnel, reducing the air supply volume and air conditioning energy consumption has certain development potential.

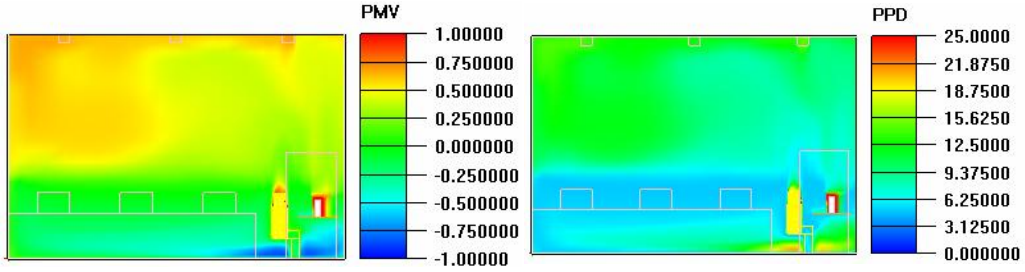
3.3 PMV-PPD Distribution



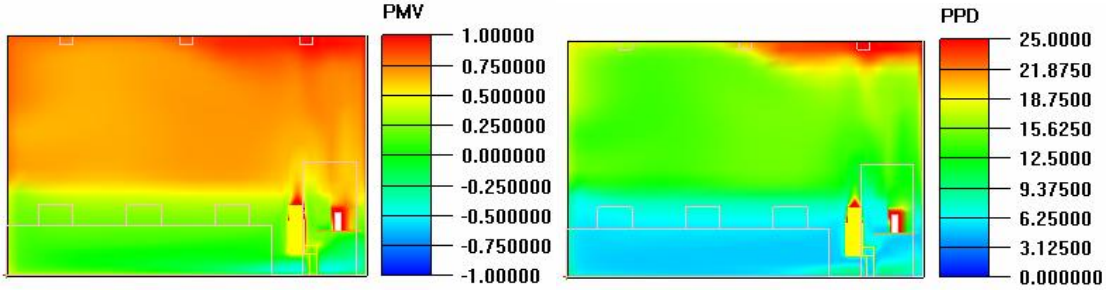
（a） PMV-PPD distribution of Z=1.8m of Condition -1



(b) PMV-PPD distribution of Z=1.8m of Condition -2



(c) PMV-PPD distribution of Z=1.8m of Condition -3



(d) PMV-PPD distribution of Z=1.8m of Condition -4

Fig.6 PMV-PPD distribution of Z=1.8m

Compare(a) with (b),(c),(d)in Figure 6.The PMV-PPD distribution with traditional jet air supply is more uniform than that with perforated ceiling air supply.However, due to the low temperature in the ankle area, the PMV is low and the PPD is high， personnel will have a cold feeling.From(b),(c),(d)in Figure 6.There is PMV-PPD stratification in the vertical direction with perforated ceiling air supply.Compare condition-3 to condition-2,except for the ankle position, the PMV in the working area is between-0.25 and 0.25, and the PPD is close to 6.25 % in condition-2.Analysis condition-3, the temperature in the lower part of the room is lower than that in condition-2, the PMV in the vertical plane is smaller than that in condition-2, the distribution of PPD in the working area is larger than that in condition-2.In the ankle area, the PMV of condition-3 is close to -1, and the PPD is about 20%,it can be considered to achieve higher thermal comfort requirements by reducing air supply.Compare condition-4 to condition-2,the average indoor PMV and PPD are higher than that of condition-2, in condition-4,the average PMV is 0.39, and the average PPD is 8.6 %, which meets the requirements of PMV and PPD in the standard [9] and eliminates the cold wind sensation at the ankle position.

4. Summary

By modeling and numerical calculation indoor air distribution of traditional jet air supply and perforated ceiling air supply, analyses and compares the indoor temperature fields, velocity fields and PMV-PPD distribution.The study mainly forms the following conclusions:

(1)Perforated ceiling air supply has good diffusivity,forming a low-speed and uniform indoor velocity field,which avoiding the air supply jet directly blowing to indoor personnel, has a good effect on alleviating the blowing feeling and improving the indoor thermal comfort.Furthermore，the airflow directly to the working range, which is conducive to the full utilization of cold airflow and has the significance of energy efficiency.

(2)The indoor flow field distribution is similar under 3 conditions of perforated ceiling air supply,The temperature profile and PMV-PPD have stratification phenomena in the vertical direction.Comprehensive comparison,the velocity field, temperature profile and PMV-PPD of condition-2 meets the requirements of grade I comfort level in the specification [9].Condition-3 reduce the distance between air supply outlet and the ground,causing the flow velocity in the working area is higher and the temperature is lower, has the potential to improve thermal comfort and save energy consumption by reducing air supply volume or increasing air supply temperature.Condition-4 indoor flow field is evenly distributed,the temperature and the PMV-PPD are generally higher than perforated ceiling air supply-1 condition.However,it meets the requirements of grade Ⅱ comfort level in the specification [9].

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