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Numerical Simulation of Indoor Thermal Environment Effected by Air Supply Temperature and Grille Angle on Stratum Ventilation in a Typical Office

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Abstract

Based on for indoor thermal environment and human thermal comfort, the air distribution in a typical air-conditioned office in the mode of stratum ventilation was simulated with the Fluent Airpak simulation software in this paper. The variation regularity of indoor thermal environment effected on air supply temperature and grille angle was explored and human thermal comfort and energy efficiency was analyzed. The following conclusions could be obtained. Under this condition with air supply angle and other parameters unchanging, air conditioning room temperature appeared overall upward trend with the air temperature increased; The average indoor wind speed appeared overall upward trend; the average indoor predicted percentage of dissatisfaction *PPD* decreased firstly and then increased. When the air temperature was 20 °C, *PPD* achieved the minimum value. When the air supply temperature and other parameters were unchanging, the average value of *PPD* was increased firstly and then decreased with the air supply angle changing. When the air supply angle was 90 degrees, *PPD* achieved the maximum value.

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Keywords: Stratum Ventilation; Numerical Simulation; Air Supply Angle; Thermal Comfort

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1. Introduction

The main nomenclatures of this article were as follows:

Nomenclature

ρ	density, kg/m ³
u	velocity, m/s
μ	laminar dynamic viscosity, kg/(m·s)
μ_t	turbulent dynamic viscosity, kg/(m·s)
t	time
ε	dissipation rate
k	turbulent kinetic energy
x	coordinate
i, j	free index
PPD	predicted percentage of dissatisfaction
PMV	predicted mean vote

With the growth of environmental pollution and world energy crisis, Asian countries have put forward that the summer indoor air temperature should be appropriately raised to respond to the energy crisis and mitigate the greenhouse effect. The mainland of China raised the summer guidance temperature of public buildings to 26 °C, and with the increase of indoor design temperature, the ANSI/ASHRAE Standard 55-2010 also recommended that the thermal uncomfortable feeling be eliminated by increasing the summer wind speed [1].

For indoor persons, the air quality in human breathing zone was directly related to the human body health and work efficiency[2]. With the consideration of these factors, a concept of stratum ventilation that applied to the small room was proposed by the City University of Hong Kong, Zhang Lin [3]. Stratum ventilation was a way of sending fresh air directly to the breathing zone by the wind-gap situated on the side wall and a little above the working area. So far, the amount of the foreign research reports in this field was rather little. T.Tchow, C.Ftsang, K.FFong, L.S.Chan by experimental and numerical studies showed that the design temperature of air-conditioned room could be improved by the stratum ventilation without compromising thermal comfortable feeling [4]. Tian Lin's study proved that good thermal comfortable feeling could be achieved by stratum ventilation [5]. Xi'an Jiaotong University, Wang Fenghao et al. have explored the airflow characteristics of the office stratum ventilation and displacement ventilation. They also have analysed the work zone under the two ventilation ways and temperature field, velocity field, CO₂ concentration field et al. near human bodies. Professor Zhang Lin reported a high temperature air conditioning study under stratum ventilation [3].

2. Theoretical model

Based on the content of this study, the mathematical model for numerical simulation would be simplified. It was that there were no other heat source and solid roadblock in addition to indoor multi-point heat sources, in the same time making the following assumptions: 1) Indoor fluid was steady and incompressible; 2) The air after being treated by air-conditioning was delivered into air conditioning room via inlet and mixed thoroughly with indoor air. The variation regular pattern of indoor temperature field could be obtained by Fluent Airpak simulation software. RNG k - ε turbulence model was set as flow model, which was similar to the standard k - ε model but more accurate. The impact of low Reynolds number was also considered in this model [6]. The transport equations for k and ε were as follows [7]:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + p_k - \rho \varepsilon \quad (1)$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_j} \left[\left(\mu + \frac{\mu_t}{\sigma_\varepsilon} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + C_{\varepsilon 1} \frac{\varepsilon}{k} p_k - C_{\varepsilon 2}^* \rho \frac{\varepsilon^2}{k} \tag{2}$$

Where, $C_{\varepsilon 2}^* = C_{\varepsilon 2} + \frac{C_\mu \eta^3 \left(1 - \frac{\eta}{\eta_0} \right)}{1 + \beta \eta^3}$, $\eta = \frac{Sk}{\varepsilon}$, $S = (2S_{ij}S_{ij})^{\frac{1}{2}}$ and $S_{ij} = \frac{1}{2} \left(\frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$. p_k was the

production of turbulent kinetic energy. S_{ij} was the mean rate of strain tensor. The values of the constants were derived as follows: $C_\mu = 0.0845$, $\sigma_k = 0.7194$, $\sigma_\varepsilon = 0.7194$, $C_{\varepsilon 1} = 1.42$, $C_{\varepsilon 2} = 1.68$, $\eta_0 = 4.38$, $\beta = 0.012$.

For the calculation of predicted percentage of dissatisfaction *PPD*, programs should be firstly compiled by MATLAB mathematics calculated software. Then calculated the predicted mean vote *PMV* that was put forward by Professor Fanger in 1970, and in the end the *PPD* value would be predicted through the following formula [8]:

$$PPD = 100 - 95 \times e^{-\left(0.03353 \times PMV^4 + 0.2179 \times PMV^2 \right)} \tag{3}$$

3. Numerical simulation model

In order to analyse the numerical simulation results of indoor air conditioning with the experimental data, the physical model of numerical simulation was established in accordance with the geometry dimension of experimental air-conditioned room, namely 6.0 m (length, x) × 4.0 m (width, y) × 3.5 m (height, z). The room set 10 point heat sources and 4 analog people that had fixed heat. The article supposed that the building envelopes' heat transfer be simply added to the heat of chamber point sources to explore this issue's study subjects. Fig. 1. was the model chart of air conditioning air supply.

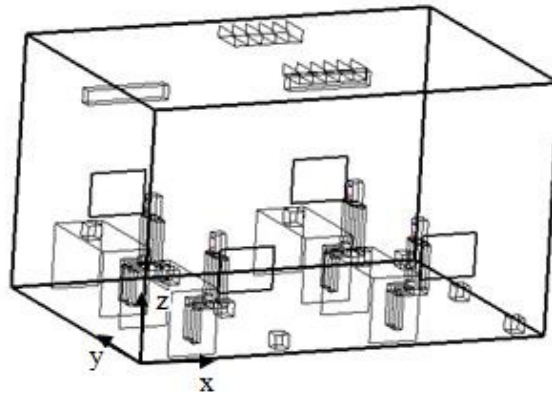


Fig. 1. the model of air conditioning air supply

4. Discussion

Fig. 2. to Fig. 6. were distribution charts of air temperature in y-z plane with the air supply temperature was constant 20°C, and respectively, the air supply angles were 30 degrees, 60 degrees, 90 degrees, 120 degrees, 150 degrees. Their temperature tangent planes lied in three section positions (x=1.5, 3.0, 4.5) where measurement points were arranged in experiment. As could be seen from the figures, at different air supply angles, the temperature within the space of human activity conformed the requirements of the design temperature basically. Only when the air supply angles were 30 degrees and 150 degrees, the indoor temperature was high, and the temperature stratification at vertical direction was very obvious under all conditions, and the return air's temperature was the highest. When the air supply angle was 90 degrees, all temperature of an air-conditioned room was the most evenly distributed, but the energy utilization

factor was lower, and was not conducive for energy saving. As the air supply angles of 60 degrees and 120 degrees, the temperature difference of head and foot was smaller, and the thermal comfort was better.

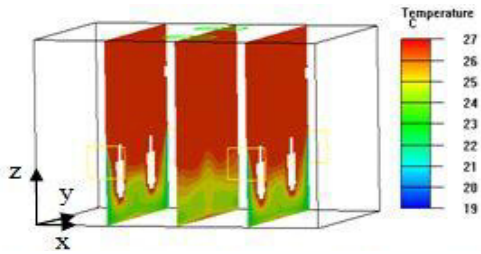


Fig. 2. the air supply angle was 30 degrees

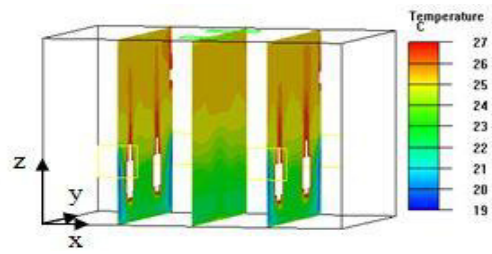


Fig. 3. the air supply angle was 60 degrees

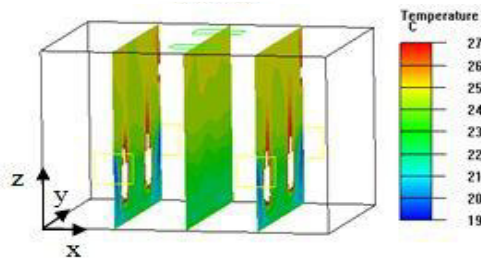


Fig. 4. the air supply angle was 90 degrees

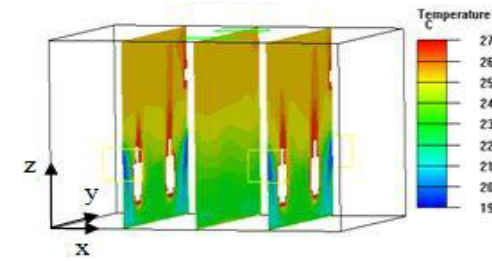


Fig. 5. the air supply angle was 120 degrees

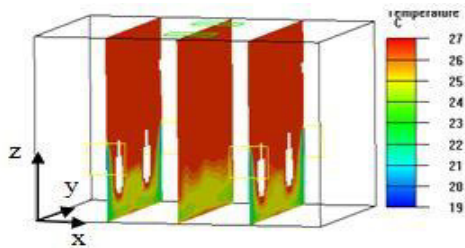


Fig. 6. the air supply angle was 150 degrees

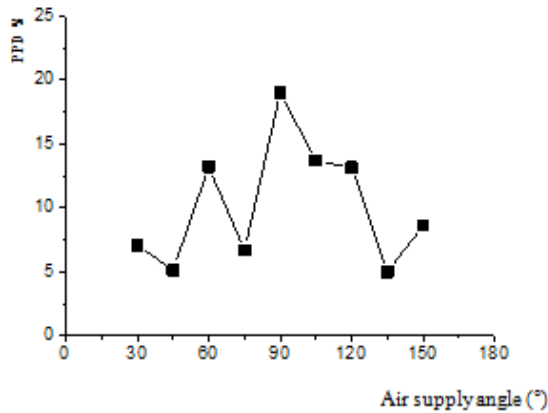


Fig. 7. the PPD in the air-conditioned room

Fig. 7. showed that under the condition of the air supply temperature unchanging, indoor predicted percentage of dissatisfaction *PPD* appeared an overall trend of changing from increase to decrease with the increase of air supply angles. When the grille angle was 90 degree, the *PPD* reached a maximum value, which larger than 10%, but did not meet the requirements of human thermal comfort. When the air supply angles were 30 degrees, 45 degrees, 135 degrees, 150 degrees, under the condition of different air supply temperature, the indoor predicted percentage of dissatisfaction *PPD* was lower than 10%, meeting human thermal comfort requirements.

Fig. 8. to Fig. 11. were distribution charts of air temperature in y-z plane with the air supply angle was constant 90 degrees, and respectively, the air supply temperature was 19°C, 20°C, 21°C, 22°C.

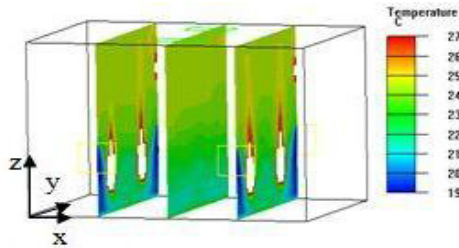


Fig. 8. the air supply temperature was 19°C

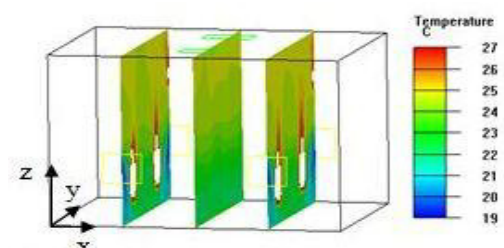


Fig. 9. the air supply temperature was 20°C

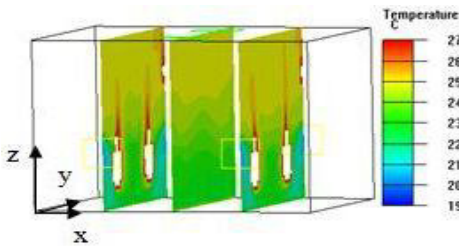


Fig. 10. the air supply temperature was 21°C

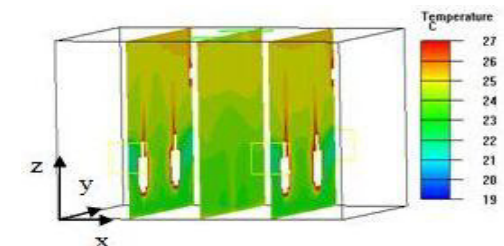


Fig. 11. the air supply temperature was 22°C

Under the air supply way of stratum air conditioning, when air supply angles and other parameters unchanging, indoor temperature and average wind speed in air-conditioned room appeared overall upward trend with the air supply temperature increased.

5. Conclusion

In the air-conditioned design, the analysis to the indoor thermal environment and thermal comfort could provide a reference for the designers selecting the appropriate stratum air supply temperature and air supply angle in design, which could improve the thermal comfort of the stratum air supply room. By exploring the impact of the stratum air supply temperature and air supply angle to indoor air temperature and the value of *PPD*, this paper could get the following conclusions:

Under the air supply way of stratum air conditioning, when the air supply angles and other parameters unchanging, air conditioning room temperature appeared overall upward trend with the air temperature increased; The average indoor wind speed appeared overall upward trend; the average indoor predicted percentage of dissatisfaction *PPD* decreased firstly and then increased. When the air temperature was 20°C, *PPD* achieved the minimum value. When the air supply temperature and other parameters were unchanging, the average value of *PPD* was increased firstly and then decreased with the air supply angle changing. When the air supply angle was 90 degrees, *PPD* achieved the maximum value.

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