Numerical simulation on the influence of air-supply velocity in air-conditioning office

Yang Ming[1+] , Yuan Dongsheng[1] and Ren Xiaoli[1]

[1]Henan Polytechnic University, School of Safety Science and Engineering, Jiaozuo, 454000

Abstract：In process of industrial production, with using some technology, it will produce lots of heat, dampness, dust and toxic or harmful gases, and will do great harm on people's physical health. The paper studied on the influence of indoor airflow field with different air-supply velocity. It established the mathematical and physical model of an air-conditioning office, and used Airpak (CFD software) to simulate the distribution of indoor temperature and velocity with different air-supply velocity. The conclusion showed the relationship of air-supply velocity with indoor temperature and airflow field. It's also evaluated the design effect by using the energy utilization coefficient. It provides the theory for designing more reasonable planning working area, and for optimize the airflow organization.

Keywords: numerical simulation; computational fluid dynamics; airflow organization; energy utilization coefficient; Airpak

1. Introduction

It can effectively remove indoor thermal and moisture load, improve personnel comfort level and the work efficiency with using reasonable mode of airflow organization in air-conditioned room[1]. Previously research show that the factors which can influence airflow organization concludes: the way of ventilation, air speed, air temperature, draught model, tuyere size and position [2].

CFD (Computational Fluid Dynamic) is an new calculation program aided design technology with the emergence of computer technology. Before the equipment installation, it can forecast the indoor air temperature and velocity with various working conditions, effective simulate airflow organization and optimize the design with using CFD[3].

In the paper, it's simulate the distribution of indoor temperature and velocity with different air-supply velocity by using Airpak(a special software for hvac) with RNG model. It's also evaluated the design effect by using the energy utilization coefficient. As a conclusion, it gives the best air-supply velocity that satisfy for the human comfort and the energy saving.

2. Physical model of air-conditioning office

According to the air-conditioning office with its practical architectural structure size, it is set up a physical model for numerical simulation which has some simplified just as Fig.1. In the model, the room's size is 5.16m×2.43m×3.65m. There are two filing cabinets, two men, two computers, two desks and six lights in the room.

+ Corresponding author. Yang Ming: Tel. + 8613603447218; Fax: +863913987881.
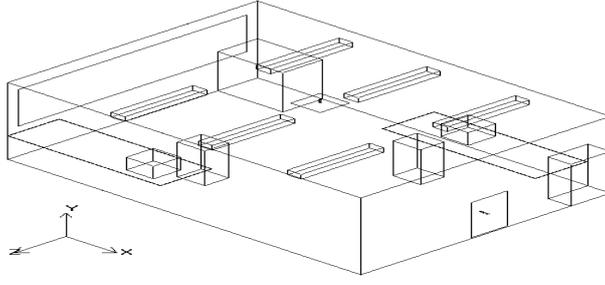 *E-mail: yming2005@163.com.*

Fig.1 Office Physical model

3. Mathematical model and boundary conditions

3.1. Mathematical model

In order to simplify the problems, there are some assumptions as fellows[4][5]：

1) The room's airflow is in low speed and can be treated as incompressible fluid and accord with Bossinesq hypothesis;

2) Airflow is a steady-state flow;

3) The room's air is transparent radiation medium;

4) It does not consider the effect of the door;

5) It does not consider the influence of air leakage and has good air tightness;

With the above assumptions, speed and temperature variable control equations are as follows:

Continuity equation： $\nabla \bullet \vec{v} = 0$

Momentum equations：

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla \cdot (\rho \vec{v} \vec{v}) = -\nabla p + \nabla \cdot (\bar{\bar{\gamma}}) + \rho \vec{g} + \vec{F}$$

$$\bar{\bar{\gamma}} = \mu[(\nabla \vec{v} + \nabla \vec{v}^t) - \frac{2}{3}\nabla \cdot \vec{v}I]$$

Kinetic energy equation：

$$\frac{\partial}{\partial t}(\rho h) + \nabla \cdot (\rho h \vec{v}) = \nabla \cdot [(\kappa + \kappa_t)\nabla T] + S_h$$

$$h = \int_{T_{ref}}^{T} C_p dT$$

RNG $\kappa - \varepsilon$ equations：

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_i}(\alpha_k \mu_{eff}\frac{\partial k}{\partial x_i}) + G_k + G_b - \rho\varepsilon$$

$$\frac{\partial}{\partial t}(\rho\varepsilon) + \frac{\partial}{\partial x_i}(\rho\varepsilon u_i) = \frac{\partial}{\partial x_i}(\alpha_k \mu_{eff}\frac{\partial\varepsilon}{\partial x_i}) + C_{1\varepsilon}\frac{\varepsilon}{k}(G_k + C_{3\varepsilon}G_b) - C_{2\varepsilon}\rho\frac{\varepsilon^2}{k} - R_\varepsilon$$

3.2. Boundary conditions

Entrance boundary: The temperature and velocity condition of supply air is shown in Tab.1

Tab.1 The temperature and velocity condition of supply air

	1	2	3
air-supply temperature T（℃）	17	17	17
air-supply velocity v（m/s）	0.09	0.15	0.2

Export boundary: it's processed by local unilateral method which assume that the node at the export interface has no effect to the first internal node. So it can let the effect coefficient is zero to the internal node. With the treatment, it doesn't need to know the value of export boundary[6].

Wall boundary[6] : indoor wall boundary conditions is set as constant temperature boundary, south wall temperature is 28℃, south window for 30℃, all the rest wall temperature are 26℃; the computer in the office is set to heat flux boundary and its heat flow were 108.5W and 173.4W; the heat flux of each lamp is always for 34W. The human body is simplified to prism form[7] and heat flow is 75W for each. The rest object boundary is set to adiabatic boundary.

4. Numerical simulation on the influence of air-supply speed change to the air distribution

4.1. Conditions with T=17℃,V=0.09m/s

It is simulated the model with air flow condition that T=17℃ and V= 0.09m/s. The typical planar: (1)the vertical plane which across point (2.53,0,1.8) and to positive axis of y axis, the level plane is y =0.1m which just across person ankle. The simulation results are shown as Fig.2~5.
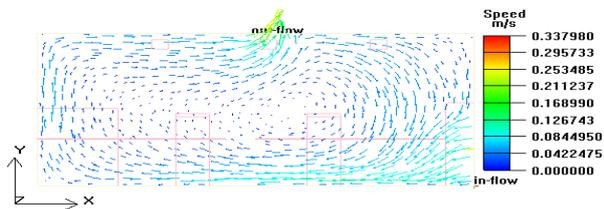

Fig.2 T=17℃,V=0.09m/s, the velocity field of
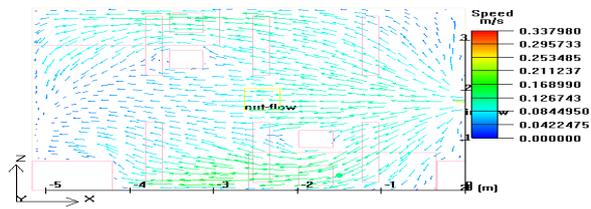the vertical section through （-2.53, 0, 1.8）

Fig.3 T=17℃,V=0.09m/s, the velocity field of
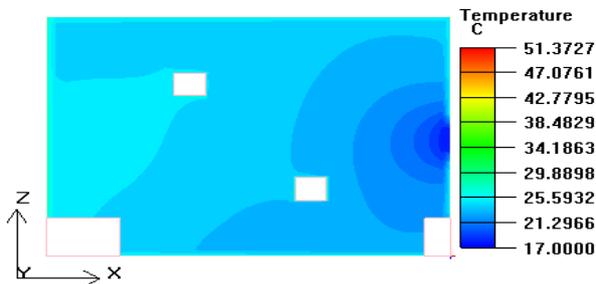the vertical section through （0, 0.1, 0）

Fig.4 T=17℃,V=0.09m/s, the temperature
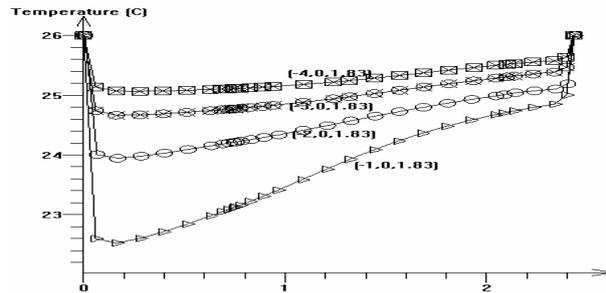field of the vertical section through （0,

Fig.5 T=17℃,V=0.09m/s, the temperature
field of the vertical section through different

From Fig.2, it can see that the cold air which carry from the bottom of the room will rise with the function of buoyancy when it meet heat dissipation body and be heated. The air also absorb the indoor air and form pinnate airflow. At the bottom or the room, the airflow is one-way flow, at the upper near to the return air mouth, the flux of pinnate airflow is more than exhaust flow, unexhausted flow was forced to fall and absorbed by pinnate airflow and formed mixed flow. From the change trend of speed, it can see that the airflow velocity is greater near the floor and the cold air will reduce to the bottom of the room because of the effects of gravity and also will rise with the function of buoyancy when it meet heat dissipation body and be heated. At the speical area ,the velocity is still greater and when the floating force decreases, the velocity also began to decline. When it arrived to the bourdary layer ,the velocity has the trend to rise when the airflow movement with the presence of vortex[8].

It can see from Fig.3 that at the plane of 0.1m above the floor, more far away to the draught ,more smaller of the air speed. And the air speed where near to the wall is more lager than to the central area. All the work area,the air speed is less than the 0.08m/s. The posibility of discomfort which caused by wind is reduced greatly at the indoor area. It can meet the requirements of the room comfortable.

From Fig.4 and Fig.5, it can see that more faraway to the draught in horizontal direction, more smaller of the temperature difference in vertical direction. And the temperature in vertical direction decreased quickly

when it is 0.1m apart from the ground. Because of the effect of the heat source, the temperature increase sharply near to the ceiling. Most area of the work place, the temperature is about 22℃~26℃. The temperature difference is about 1℃ from the head to the ankle when people is in sitting postures. But within the scope about 1m3 close to the draught, the temperature is less than 22℃, and when people is in these places,it will feel cold. It does not meet the requirement of comfort for human[9].

4.2. Conditions with T=17℃,V=0.15m/s

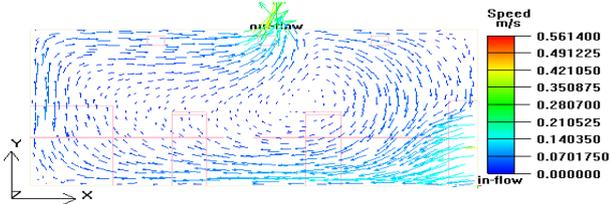The typical temperature and velocity distribution is shown as Fig.6~9 with air flow condition that T=17℃and V=0.15m/s.

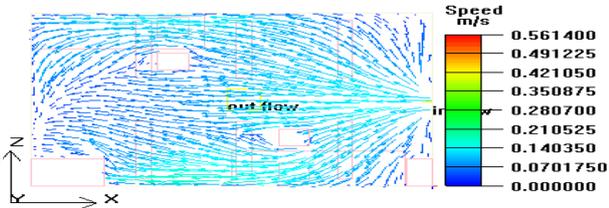Fig.6 T=17℃,V=0.15m/s，the velocity field of the vertical section through （-2.53，0，1.8）

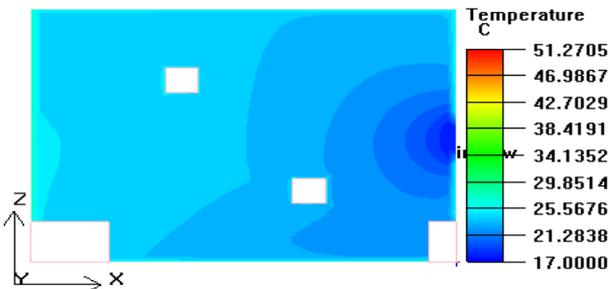Fig.7 T=17℃,V=0.15m/s，the velocity field of the vertical section through （0，0.1，0）

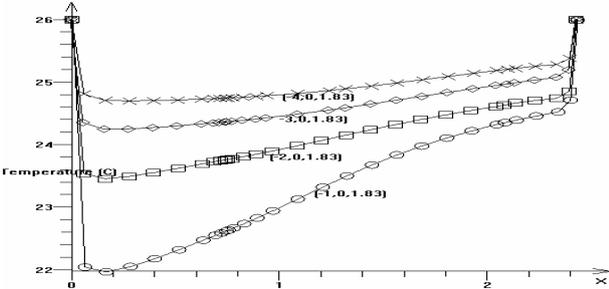Fig.8 T=17℃,V=0.15m/s，the temperature field of the vertical section through （0，0.1，0）

Fig.9 T=17℃,V=0.15m/s，the temperature field of the vertical section through different points

Compared with Fig.2 and Fig.3, it can see from Fig.6and Fig.7 that when the air-supply velocity rised, the air flow forms and features did not change in the office and only increased the air speed at the same position. The speed of the whole work area are less than 0.14m/s. It is greatly reduced the chance of discomfort that caused by the air blow in the work area in the office. And the condition can satisfy the requirements for room comfortable. Compared with Fig.4 and Fig.5, it also can see from Fig.8and Fig.9 that when the air-supply velocity rised, the airflow has great influence and the temperature will dropped at the same position because of the cold air. The temperature gradient will increase on the vertical direction of same point. The scope that near the draught and its temperature less than 22℃will expand. It also expand the scope that people feeling cold and uncomfortable.

4.3. Conditions with T=17℃,V=0.20m/s

The typical temperature and velocity distribution is shown as Fig.10~13 with air flow condition that T=17℃and V=0.20m/s.
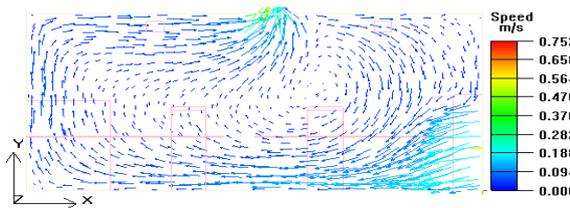

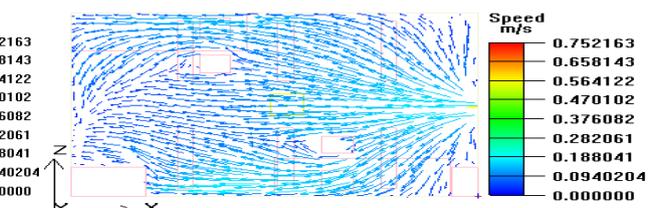Fig.10 T=17℃,V=0.20m/s，the velocity field of the vertical section through （-2.53，0，1.8）

Fig.11 T=17℃,V=0.20m/s，the velocity field of the vertical section through （0，0.1，0）

Fig.12 T=17℃,V=0.2m/s，the temperature field of the vertical section through （0，0.1，0）
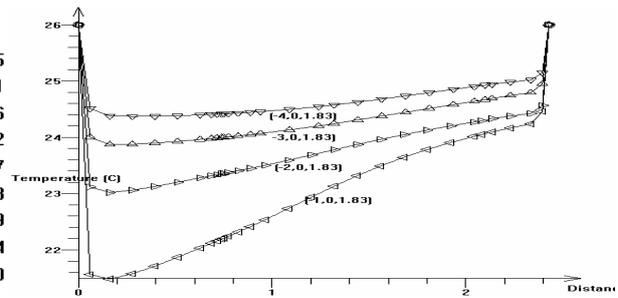

Fig.13 T=17℃,V=0.2m/s，the temperature field of the vertical section through different points

Compared with Fig.6 and Fig.7, it can see from Fig.10and Fig.11 that when the air-supply velocity rised, the air flow forms and features did not change in the office and only increased the air speed at the same position. The speed of the whole work area are less than 0.19m/s. Compared with Fig.8 and Fig.9, it also can see from Fig.12and Fig.13 that the temperature gradient will discrease on the vertical direction of same point. And the other characteristics of the office has the same trend with the sample of section 4.2.

4.4. Comparision of the energy utilization coefficient of the above three conditions

The comparision of the energy utilization coefficient of the above three conditions just as Tab.2.

Tab.2   Comparation of the energy utilization coefficient

	1	2	3
the energy utilization coefficient(η)	1.0559	1.0668	1.0778

From Tab.2, it can see that there are little difference of the energy utilization coefficient of the above three conditions.

5. Conclusion

In the paper, it has simulated the temperature and velocity distribution of air-conditioning office with different air-supply velocity by using a software Airpak. With the analysis, it can get the conclusions as follows:

1) If it keep the air-supply temperature as constant and only change the air-supply speed less than 0.2m/s, the airflow form nearly keep the same. The only difference is the value of air velocity in the same position. It also can know that the air velocities of whole work area are less than 0.19m/s. It can meet the requirement of comfort for human and people nearly cannot feel unconfortable because of air-supply. But if the air-supply speed is more than 0.2m/s, the speed of most area where across people ankle will greater than 0.2m/s, and it will be unconfortable for human and cannot meet for the requaiement.

2) When the air-supply speed increases, the influence of the indoor area will increase because of cold air. The regular is the temperature will drop in the same position. The temperature gradient in vertical derection will increase when V= 0.15m/s and will discrease when V= 0.20m/s.

3) It has little difference of the energy utilization coefficient by the three sample.

4) From the analysis, it can get the conclusion that the suitable air-supply speed in an air-conditioning office is from 0.15 m/s to 0.20m/s which people will feel satisfy.

6. References：

[1]   Zhao Rongyi. Air conditioning(the 3rd version)[M]. Beijing: China Architecture & Building Press, 1994.1～3.

[2]   Yang Aiping. Indoor Air Quality and Its Influencing Factors[J]. Refrigeration, 2005,24(2):33～36.

[3]   Tao Wenquan. Recent advances in numerical heat transfer[M]. Beijing: Science Press,2000.193.

[4]   AIRPAK(ver.2.1) DOCUMENTATION.

[5]   S.V.Patankar. Numerical heat transfer and fluid flow [M]. Beijing: Science Press,，1984.13～18.

[6] Tao Wenquan. Numerical heat transfer(the 3rd version)[M]. Xi'an: Xi'an Jiaotong University Press1988.

[7] Pan Yiqun , Long Weiding and Fan Cunyang. Indoor air quality and fresh air in office buildings[J]. Heating Ventilating & Air Conditioning. 2002.32（6）：28-30

[8] WU Xuehui,LI Xiao-dong. Thermal comfort of stands zone about displacement ventilation system in large space buildings[J]. Journal of Harbin Institute of Technology. 2008.40(8):1256-1260

[9] Ministry of Construction of PRC.Code for design of heating ventilation and air conditioning（GB 50019-2003）[S].Beijing:China Planning Press,2009.