Analysis of Cold Air Distribution System in an Office Building by the Numerical Simulation Method

Yiwen Jian

Beijing University of Technology

jianyiwen@bjut.edu.cn

Dan Li   Hongqing Xu   Xiaojun Ma

Beijing Institute of Architectural Design

Beijing, P.R.China

maxj@biad.com.cn

Abstract: Numerical simulation is carried out in this paper to calculate indoor air patterns, which include angles of inlet direction and induced ratios in a typical official room.

According to the simulation results, the indoor air distribution and indoor thermal environment of occupied zone are analyzed. The results can serve as advice for future design of similar buildings.

Key words: Cold air distribution system, Indoor Air pattern, Numerical simulation, ADPI

1 INTRODUCTION

Cold air distribution system can make full of use the cold water which is directly supplied by ice storage system. Consequently, it can reduce the supply air temperature and increase the temperature difference between supply air and indoor air without increasing cost of making cold water. It also can save the energy and improve the indoor air quality and thermal comfort. Cold air distribution system has many advantages, which have been approved in practices.

However, cold air distribution system also has some problems that affect its application [1]. The most important items are the difficulty to control the air flow pattern caused by the large temperature difference between supply air and indoor air, and the lack of the measure to forecast the form of flow. This will result in the deterioration of the indoor environment. Therefore, how to choose the proper diffuser to obtain perfect air flow pattern is the key in engineering design of indoor environment [2].

Generally speaking, air temperature and air velocity are the two important factors to determine human comfort, while the change of the relative humidity from 30％ to 70％ will cause little discomfort to human. Therefore, considering the integrate effect of air temperature and air flow velocity, the Air Diffusion Performance Index (ADPI) is introduced to evaluate the effect of the indoor air distribution on human comfort.[3] The Effective Draft Temperature (EDT) is defined as the following equation,

$$EDT = (t_i - t_n) - 7.66(u_i - 0.15) \quad （1）$$

Where, t_i , u_i , t_n are the local air dry-bulb temperature, air velocity and control room dry-bulb temperature of indoor given spots. It is recognized that, when the EDT is between -1.7 and +1.1, a high percentage of people are comfortable. Therefore the ADPI should be,

$$ADPI = \frac{Numbers(-1.7 < EDT < 1.1)}{TotalNumbers} \times 100\% \quad （2）$$

It is observed that high percentage of people who feel comfort, the ADPI value is large. Normally, the optimal ADPI value should be over 80％.

2 DESCRIPTIONS

A typical room with cold air distribution is analyzed by numerical method in this paper. The room is a 290m^2 area's office, which with one-side outward wall. There are 8 single-side outlets and 8 double-side outlets of HILT-type cold air diffusers that are set on ceiling; each diffuser's air volume is 340m^3/h. And there are 4 return air inlets that are set

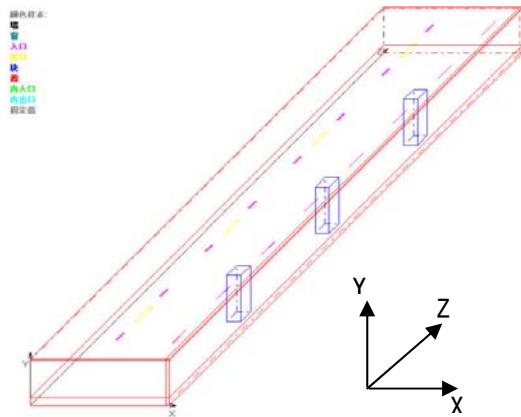on ceiling too. Figure 1 shows the physical model of the room.

Fig. 1 Physical model of the room

A new zero-equation turbulence model was introduced in this simulation.[4] The validation of the zero-equation turbulence model in simulating indoor airflow pattern has been studied.[5] The disperse method is finite volume method. Momentum equations adopt stagger grids. ADI method is used to solve the liner equations. The SIMPLE arithmetic is adopted as the simulating platform. The above methodology used in this work can be processed by the Tsinghua three dimensional CFD simulation program.

The indoor air temperature distributions are simulated with different angles of inlets directions and mix temperatures of induced air. The results of simulation will be discussed in the following sections.

3 RESULTS AND DISCUSSIONS

3.1 Angle of inlet direction

Figure 2 to figure 4 show the simulation results of indoor air distributions with 45°, 60°and 75°angles of inlets directions. With lower angle (45°), the air flow can reach the occupied zone where the air velocity is about 0.2 to 0.5 m/s. Such uncomfortable draught could disturb office workers when the inlet air temperature is too low. The simulated air patterns show that stasis-areas will occur obviously in space if the angle of inlet direction is lower. In these stasis-areas the air flow is slowly and the local heat volume will be exhausted hardly, so that the ununiformity of indoor air temperature is present.
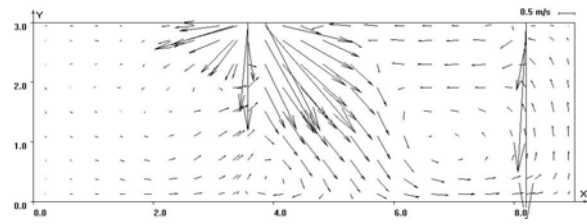

Fig. 2 Air velocity distribution with 45°inlet direction

When the angle of inlet direction turns higher, the uncomfortable draught becomes weaken. At the same time, the controlling area of air inlets enlarged with the indoor air movement improved, the stasis-area of air flow is nearly disappeared. With 75°of inlet direction, as Figure 4 shows, the air flow pattern of inlets is closed to ceiling-attachment status, and the occupied zone is almost in the return air flow zone where less draught occur. The indoor air distribution becomes better.
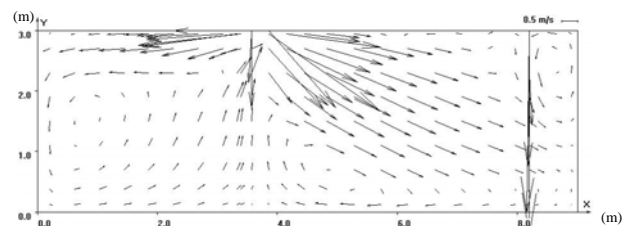

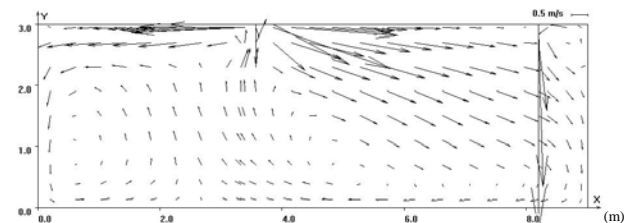**Fig. 3 Air velocity distribution with 60°inlet direction**

Fig. 4 Air velocity distribution with 75°inlet direction

According to the analyses above, when the cold air inlets are adopted, the angle of inlets direction have remarkable affects on indoor air distribution and human comfort. With the bigger of the angle, the indoor air environment is better. When the inlet air flow is close to ceiling-attachment status, the occupied zone is almost in the return air flow zone. This condition is favorable for the cold air inlet system.

3.2 Induced ratio of air inlet

The induced ratio of inlet determines the air

mix temperature, and then affects the air temperature distribution of occupied zone. In this paper, the indoor air pattern will be simulated by different air mix temperatures determined by the induced ratio of inlets. The simulation conditions include, no induction (supply air temperature is 8.5), induced ratio is 10 (mix air temperature is 10), and induced ratio is 33 (mix air temperature is 15). Based on simulation, the indoor air environments are analyzed.

Figure 5 to 7 show that the air temperatures distribution of occupied zone with the above three different mix air temperatures.
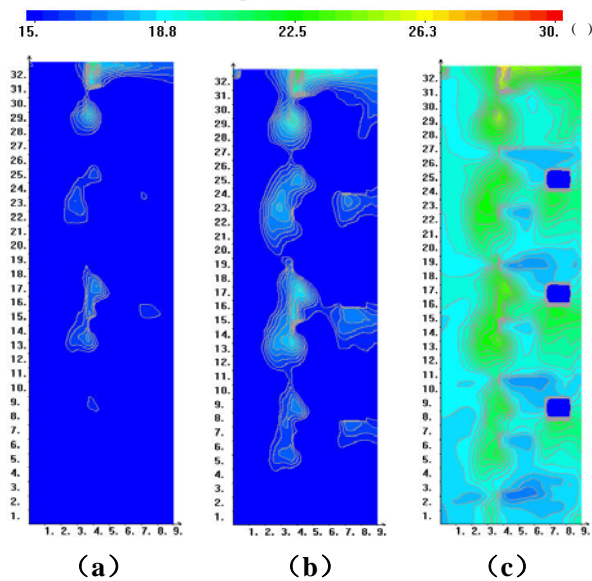

（a）   （b）   （c）

Fig. 5 Air temperature distributions of occupied zones with 45°of inlet direction

Figure 5 shows the air temperature distributions of occupied zones with 45°of inlet direction, in which the (a) is with mix air temperature 8.5 , (b) is with mix air temperature 10   and (c) is with mix air temperature 15 . The indoor air average temperature increases by increasing air mix temperature of inlet. When the mix air temperature is low, the indoor air average temperature is not more than 20 . And when the mix air temperature is 15   with the induction rate increases markedly, the indoor air average temperature rises to 22 . However considering of the ununiformity of air temperature, that the low temperature near the inlet is 17.2   and the high temperature in stasis-areas is 29.1 , the indoor air pattern is not ideal.

When the angle of inlet direction is 60°as shown in Figure 6, which the (a), (b) and (c) are

symbols as the same conditions as Figure 5, the indoor air average temperature is improved than that with 45°of inlet direction. Because of the change of inlet direction, the cold air blowing to human body directly is weakened. When the mix air temperature is 8.5 , that is no induction, the indoor air temperature is fairly low. And when the mix temperature is increased to 15 , the indoor air average temperature reaches to 24.1 . Compared with the condition of 45°inlet direction, the stasis-area shrinks obviously. As a whole, the uniformity of indoor air distribution is improved.
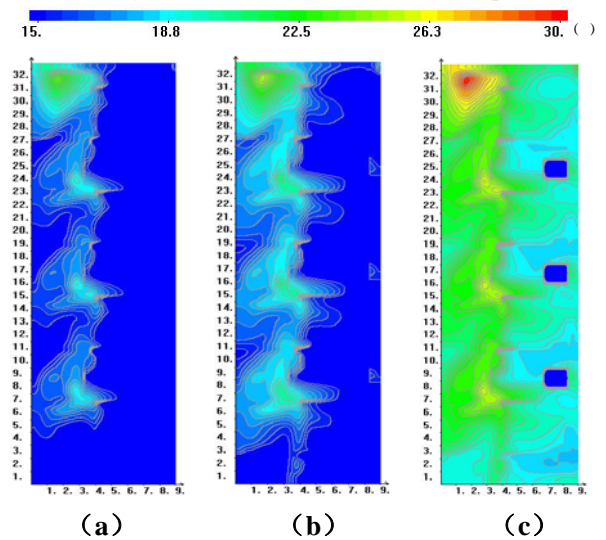

（a）   （b）   （c）

Fig. 6 Air temperature distributions of occupied zones with 60°of inlet direction
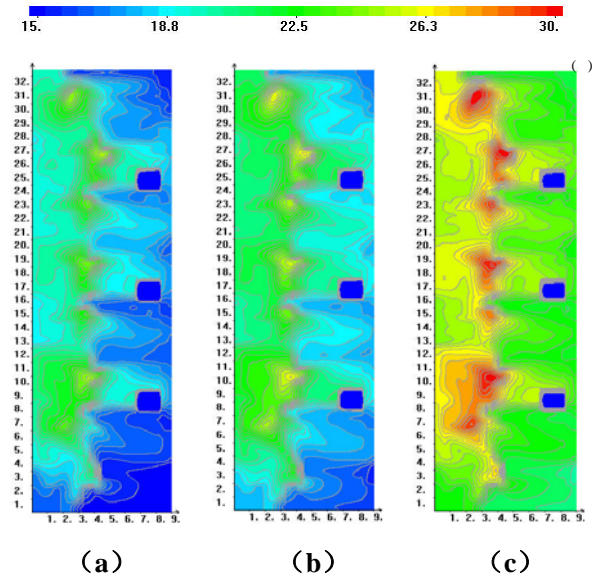

（a）   （b）   （c）

Fig. 7 Air temperature distributions of occupied zones with 75°of inlet direction

Figure 7 shows the air temperature distributions of occupied zones with 75°of inlet direction under three different mix air temperatures,

in which the (a), (b) and (c) are symbols as the same conditions as Figure 5. Because the inlet direction is nearly close to ceiling-attachment status, there is no stasis-areas occurred. Compared with the two conditions above (Figure 5 and Figure 6), the indoor air temperature distribution has been improved greatly, although their distribution trends are familiar. It is should be noted that, the improvement is greater with higher mix air temperature (higher induction ratio). When the mix temperature is 15 , the indoor air average temperature is 26.1 , which increases greater than the other conditions.

Results show that the air flow patterns with different inlet directions are similar with each other, and the induction ration has great influence on indoor air environment, especially on temperature distribution of occupied zone.

Figure 8 shows the ADPI values of occupied zone. When the mix temperature (induced ratio) of inlet is remains constant, because the cold air is not blow to the occupied zone directly, the ADPI value increases distinctly with the increasing of angle of inlet direction. And the air pattern of occupied zone is improved obviously. For the same reason, when the angle of inlet direction is 45°, the change of induced ratio is not remarkable in improving satisfaction of indoor air environment. However, with the angle of inlet direction more increasing, the influence of induced ratio is greater. The ADPI value reaches 80% when the mix air temperature is 15 .
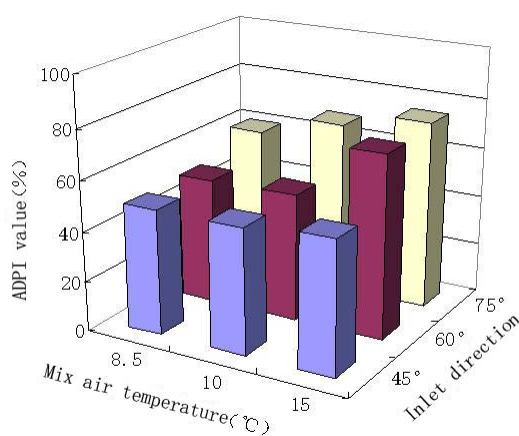

Fig. 8 Statistics of ADPI values of occupied zone

Comparing the ADPI values of occupied zones with different given conditions, it is included that, the indoor air environment with cold air distribution system is improved by either raising inlet direction or increasing inlet induced ratio. Raising inlet direction can avoid the cold air from blowing to human body directly, and increasing inlet induced ratio can satisfy the indoor human comfort and can save the energy consumption.

4 CONCLUSIONS

By changing inlet direction or by changing inlet induced ratio, the indoor air environment with cold air distribution system can be affected. To maintain the human comfort of occupied zone, high degree of the angle of inlet direction is recommended, which can prevented the cold air from blowing to human body directly. Inlet with high induced ratio is recommended too, which can increase the mix air temperature and then make the indoor air distribution better.

Comparison of ADPI values of occupied zones under different conditions shows that, for cold air distribution system, increasing the degree of inlet direction angle or the induced ratio can improve the indoor thermal environment, and achieve the goal of saving energy. When the induced ratio goes to a certain level, the mixed temperature will increases obviously, which almost equals to the normal air-condition system. And, in order to keep the safety and reliability of the cold air distribution system, we should choose to increase the induced ratio because the influence of the inlet direction is relative less.

Based on an engineering project, the indoor air pattern with cold air distribution system is simulated and analyzed in this paper. The simulation conditions include different angles of inlets directions and different mix temperatures of induction air. Some conclusions are drawn as above, that could be as references to similar engineering project's design.

REFERENCES

[1] J.S Elleson. Energy use of fan-powered mixing boxes with cold air distribution. ASHRAE Trans,1993, part two:1349~1358.

[2] Yanlin ZENG, Deyuan CAI, Yingqing LIU. The research of diffusers used in cold air distribution

system. Transaction of Chongqing University[J]. 1997, 19(5): 73~77.

[3] Zhaofen JIN, Yingxin ZHU. Built Environment. Beijing: China Architecture & Building Press, 2001.(In Chinese)

[4] Qinyan CHEN, Weiran XU. A zero-equation turbulence model for indoor air flow simulation. Energy and Building, Vol 28(1998), pp 137-144.

[5] Bin ZHAO, Xianting LI, Qisen YAN. Simulation of indoor airflow in ventilated room by zero-equation turbulence model. J Tsinghua University, Vol 41,No.10(2001), pp 109-113. (In Chinese)