Research of Thermal Comfort for Side Air Supply Pattern in Office

Wenhong Yu¹, Sichen Tong¹ and Chao Zheng²

¹North China University of Technology, 100144, Beijing, China
²Beijing Mechanical and Electrical Engineering Group Co., Ltd., 100045, Beijing, China

Abstract: With the development of the times, people begin to pursue a healthy and comfortable indoor environment. The bad quality of the indoor environment will not only affect the health of the office staff, but also affect the efficiency of the office staff. In this paper, the indoor design parameters are measured on cooling condition in the summer and heating condition in the winter. The indoor air distribution is numerically simulated. By analyzing the air distribution, temperature distribution and thermal comfort evaluation index (PMV-PPD) of the side air supply pattern, the indoor air distribution and thermal comfort of the side air supply pattern were evaluated.

1. Introduction
With the development of the times, people begin to concern healthy and comfortable of indoor environment. The bad quality of the indoor environment will not only affect the health of the office staff, but also affect the efficiency of the office staff. In order to satisfy the requirement of the thermal comfort of the office staff, the requirement of the office indoor air quality and air distribution is getting higher. The side air supply pattern can satisfy the requirement of outlet diffusion, temperature distribution and velocity distribution, which are widely used in the air conditioning system, and its pipeline arrangement is simple and the construction is convenient [1]. This paper provides a basis for the boundary condition of numerical simulation by measuring the indoor design parameters of the office. We simulate the air distribution; temperature distribution and thermal comfort evaluation index (PMV-PPD) of the room by using Airpak. The indoor air distribution and analyzing thermal comfort of the side air supply pattern were evaluated in the two conditions.

2. Thermal comfort of human body
The index of human thermal comfort is represented by the famous Predicted Mean Vote and Predicted Percentage of Dissatisfied by Professor Fanger of Denmark. The PMV index is based on the ASHRE comfort area of seven comfort levels (-3 cold, -2 cool, 1 slightly cold, 0 moderate, +1 slightly warm, +2 warm, +3 hot), given by the thermal comfort index in numerical form. It is based on two personal factors, clothing resistance (clo) and activity degree (met) and several natural factors (air temperature, average radiation temperature, air flow velocity and humidity) [2]. The PMV index represents the heat and cold sense of the majority of person in the same environment, so it can be used to evaluate the thermal environment comfort. However, due to the individual differences, the PMV is not necessarily representing the feelings of all persons. Therefore, the PPD is proposed indicating the percentage of the person not satisfied with the thermal environment.
ISO proposes a standardized method for indoor thermal environment assessment and measurement. ISO7730 stipulates: The vertical temperature between 0.1 m–1.1 m is not greater than 3°C (that is between the head and foot of the sitting). According to the National Civil Architecture Engineering Design Technical Measures-2009 (HVAC Power) [4], the comfortable air velocity should be controlled around 0.3 m/s in summer and should be controlled around 0.2 m/s in winter.

3. Field measurement
The research object is a university's office building in Beijing, the room is set up 13 work desks (Figure 1). The west wall is an exterior wall, the north and south wall is an interior wall. Considering the length of the room is so long, the individual side air supply pattern may not satisfy the requirement of the thermal comfort of the person, so the pattern of air conditioning supply selects the air diffuser and double shutter combination scheme.

3.1 Measuring equipment
By using the hot-wire anemometer to measure the air velocity of the air outlet, which has the advantages of portability and high cost performance. The temperature and relative humidity of the air outlet is measured by separate thermos-hygrometer.

3.2 Measuring results
The temperature, relative humidity and air velocity of the air outlet are measured on cooling condition in the summer and heating condition in the winter. The results of temperature, humidity and air velocity are average measurement. In order to reduce the measured error, the air conditioning system should be measured when the system running stably. The measured results of the two conditions see Table 1 and Table 2. The result of the measured is used as a basis for the boundary condition parameter setting of the numerical simulation.

| Table 1. Air supply status on cooling condition in the summer |
|-------------------------------------------------------------|
| Air diffuser | Double shutter |
| Temperature (°C) | 19 | 19 |
| Humidity (%)   | 25 | 25 |
| Air velocity (m/s) | 2 | 2 |
Table 2. Air supply status on heating condition in the winter

|                | Air diffuser | Double shutter |
|----------------|--------------|----------------|
| Temperature (°C) | 30           | 30             |
| Humidity (%)    | 25           | 25             |
| Air velocity (m/s) | 2.2       | 2.5            |

4. Numerical simulation

4.1 Physical model
According to the actual use of the room and the structure of the room, after an appropriate simplification, the physical model is shown (Figure 2). There are 13 persons in the room, each person have a computer. And there are also 18 lights in the room. According to the measured data, the size of the air outlet and their exact position in the model can be determined.

![Figure 2. Physics model of the office.](image)

4.2 Mathematical model
The air flow of air conditioning system is the constant of incompressible fluid, which must satisfy the law of conservation of mass, law of conservation of momentum, energy conservation law and law of conservation of composition [5]. The general form is:

\[
\frac{\partial (\rho \phi)}{\partial t} + \text{div}(\rho u \phi) = \text{div}(\Gamma \text{grad} \phi) + s
\]

In the formula: \( \phi \) is universal variable, \( \phi \) can represent variables such as \( U, V, W, t \), etc., is velocity vector, \( \Gamma \) is general diffusion coefficient, \( s \) is source term.

To solve the different types of flow and heat transfer problems, fluid control equations can be used as a general form of the differential equation.

4.3 Boundary Condition and solving model
The next rooms in the room are also air conditioning rooms, so the boundary condition of the exterior walls set in the heat insulation wall. The boundary condition at the outer wall and the outer window set to the fixed temperature wall. Set parameters for each object (Table 3).

| Name         | Number | Size            | Type    | Boundary Condition | Value          |
|--------------|--------|-----------------|---------|--------------------|----------------|
| Outer wall   | 1      | 8.4 m×3 m       | walls   | fixed temperature  | summer: 28°C   |
|              |        |                 |         |                    | winter: 18°C    |
| Inner wall   | 5      | —               | walls   | heat insulation     | —              |
| Western window | 2     | 3.6 m×1.5 m     | walls   | fixed temperature  | summer: 32°C   |
|              |        |                 |         |                    | winter: 16°C    |
| Door         | 1      | 1.4 m×1.8 m     | Partitions | heat insulation     | —              |
Using MESHER-HD hybrid grid to division the graduate office, the hybrid grid can automatically classify any complex geometric shapes compare with tetrahedron grid and hexahedral grid.

5. Numerical simulation results and analysis

5.1 Cooling condition in the summer

The air velocity of the air diffuser is 1.7 m/s, the air velocity of the double shutter is 2 m/s, and the air supply temperature is 19°C in the summer. The results of numerical simulation in the summer by using Airpak (Figure 3- Figure 10). When calculating the PMV index and PPD index, assuming the body clothing thermal resistance is 0.4 clo.

Figure 3. Velocity vector of air diffuser (XOY axis).

Figure 4. Velocity vector of double shutter (XOY axis).
It is shown from the Figure 3 that the cold air is provided by the air diffuse has an effect on the 1/3 areas near the door. Because the diffuser's cold air is spread to the surrounding, the staff at the bottom of the office without a cold sense. It is shown from the Figure 4 that the cold air is provided by the double shutter has an effect on the 2/3 areas near the window. The cold air is produced by the double shutter can basically reach the outer window, ensuring the area near the outer window is in the "backflow zone", and the cold air and the indoor air can be fully mixed. In a word, the air velocity of each station is low, about 0.25 m/s. The office staffs have a better sense in the room.
It is shown from the Figure 5 and Figure 6 that the temperature distribution is well in the room, form 23°C to 25°C, there is no obvious too cold or heat area. The temperature in the area near the air outlet is low, but the temperature near the outer window is high.

It is shown from the Figure 7 that the PMV values of Y=0.1 m in the office is more uniform, at around -0.5. It is shown from the Figure 8 that the PMV values of Y=1.1 m in the 11, 12, 13 stations, at around -0.8. In a word, the PMV values of the room are within the range of thermal comfort standards, between -1 to 1.

It is shown from the Figure 9 that the PPD values of Y=0.1 m is lower on the east side than the west side of the room, at around 5%. Due to the effect of the outer window, the PPD values of Y=1.1m on the west side of the room will be higher, between 5% and 25%. In a word, the PPD values are within acceptable limits in the room.

5.2 Heating condition in the winter

The air velocity of the air diffuser is 2.2m/s, the air velocity of the double shutter is 2.5 m/s, and the air supply temperature is 30°C in the winter. The results of numerical simulation in the winter by using Airpak (Figure 11- Figure 18). When calculating the PMV index and PPD index, the body clothing thermal resistance is 1.0 clo.

Figure 11. Velocity vector of air diffuser(XOY axis).

Figure 12. Velocity vector of double shutter(XOY axis).
It is shown from the Figure 11 that the heat air is provided by the air diffuse has an effect on the 1/3 areas near the door. It is shown from the Figure 12 that the heat air is provided by the double shutter has
an effect on the 2/3 areas near the window. The heat air is produced by the double shutter can basically reach the outer window, ensuring the area near the outer window is in the “back-flow zone”, and the heat air and the indoor air can be fully mixed. In a word, the air velocity of each station is low, about 0.20m/s. The persons have a better sense of the room.

It is shown from the Figure 13 and Figure 14 that the temperature distribution is more uniform in the room, from 26°C to 28°C, there is no obvious too cold or heat area. The temperature is low in the area close to the outer window, about 24°C.

It is shown from the Figure 15 that the PMV values of Y=0.1 m in the office is more uniform, at around -0.5. The PMV values on the west side of the room are high, especially near the outer window area. It is shown from the Figure 16 that the PMV values of Y=1.1 m, between -0.5 to 0.5. In a word, the PMV values of the room are within the range of thermal comfort standards, between -1 to 1.

It is shown from the Figure 17 and Figure 18 that the PPD values on the east side of the room is lower than that on the west side, at around 5%. The PPD values on the west side of the room will be higher in the area near the outer window, between 8% and 25%. In a word, the PPD values are within acceptable limits in the room.

In this paper, the results of numerical simulation of indoor air velocity, temperature and thermal comfort are analyzed, the air conditioning pattern used is reasonable with the use of air diffuser and double shutter in two conditions in this office. The quantity and position of the outlet are reasonable. The indoor air distribution of the office is better in two conditions, which ensures that most of the area in the “back-flow zone” and there is no obvious “dead zone”. Person feels comfortable, which basically satisfy the persons on the thermal comfort requirements.

6. Conclusion

In this paper, the measurement and numerical simulation analysis of a university's office the side air supply pattern are carried out. The following conclusions are drawn:

The side air supply pattern is well, indoor air distribution is reasonable: the persons feel comfortable and satisfy the requirement of thermal comfort. Because the length of the room is so long, it is possible that close to the outside window cannot be in the return area, and the person near the external window usually will feel too cold or too hot. The side air supply pattern designed for the room effectively solves this problem. It shows that the side air supply pattern used by the air diffuser and the double shutter is reasonable in this room, which can provide a reasonable reference for the design of the air conditioning system of the same type of office. The quantity and position of the outlet are reasonable. The indoor air distribution of the office is better in two conditions, which ensures that most of the area in the “back-flow zone” and there is no obvious “dead zone”. Person feels comfortable, which basically satisfy the persons on the thermal comfort requirements.

Reference

[1] Cao Guoqing. Numerical simulation and analysis of indoor air distribution on three side air supply pattern [J]. Heating&Refrigeration, 2006 (09): 44-47.
[2] Zhu Yingxin. Architectural Environmental Science (second edition) [M] Beijing: China Construction Industry Press, 2009.
[3] ISO standard 7730-84. Moderate thermal environments determination of PMV and PPD indices and specification of the condition for thermal comfort. International Standards Organization, Geneva, 1984.
[4] National Civil Architecture Engineering Design Technical Measures-2009 (HVAC Power) [M] Beijing: China Planning Press.
[5] Tang Guangfa. Numerical calculation and model test of indoor air distribution [M] Changsha: Hunan University Press, 1989.