Numerical Simulation and Analysis of Thermal Environment in Air-Conditioning Office Building

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Abstract: The Airpak software is used to simulate the thermal environment in the office of three air supply angles (0°, 45° and 60°) of cabinet air conditioner in summer. Through analysis of the simulation results about the velocity distribution and the temperature distribution in the indoor air flow under three operating conditions, it is found that the thermal comfort of the room is the best in the case of the upward air supply of 45° angle. The optimization of air conditioners should not only consider thermal comfort, but also reduce energy consumption of air conditioners to achieve building energy efficiency.

1. Introduction
With the rising standard of living, air conditioner has become a necessity in summer. At the same time, air conditioner may also bring some problems, such as a strong sense of blowing, a bad age local air and the aggregation of pollutants. The unreasonable air distribution in the air conditioning system will not only reduce the thermal comfort of the personnel, increase the initial investment and operation cost of the equipment, but also lead to the waste of building energy consumption. In order to create a comfortable indoor thermal environment, Airpak software was used to simulate the indoor air environment and analyze the velocity distribution and temperature distribution of airflow to get higher thermal comfort.

2. Physical model and boundary conditions

2.1 Physical model
This paper takes an office as an example to analyze the thermal comfort of cabinet air conditioner. The distribution of the actual building work desk and indoor equipment in the office are shown in Figure 1. The dimensions of the room are: length × width × height = 7.5m × 7.2m × 3.3m. The interior has 8 persons, and everyone has a computer and a small closet in his work desk. There is also a large bookcase, six lamps and a cubicle air conditioner (Cabinet air conditioner: Haier, KFR-120 LW/L). The air conditioner is placed in the northwest corner of the room, limited by the size of indoor machine and the layout of the room and the length of refrigerant pipe.
2.2 Boundary condition

The density of the indoor air is in accordance with the Bossinesq hypothesis. The air flow in the room is steady-state turbulence, ignoring the air leakage effect of the door and the window. The outdoor air temperature in summer is 30 degrees. Indoor heat source mainly considers personnel, computer and lamp cooling. PMV-PPD is calculated in accordance with the staff sitting in the seat. Personnel metabolic rate is 58 W/m$^2$. Clothing thermal resistance is 0.08 m$^2$.k/W. Air temperature, radiation temperature, relative humidity and air velocity are calculated according to the results of numerical simulation. The boundary conditions for the numerical simulation are shown in Table 1.

### Table 1. Numerical simulation of boundary conditions.

| Name         | Number | Size                  | Model Type | boundary condition         | Value                     |
|--------------|--------|-----------------------|------------|-----------------------------|---------------------------|
| Room         | 1      | 7.5m×7.2m×3.3m        | room       | Constant temperature        | Exterior wall: 40°C       |
|              |        |                       |            |                              | Interior wall: 28°C       |
| South window | 2      | 1.2m×1.7m             | walls      | Constant temperature        |                           |
|              |        | 3.2m×1.7m             |            | Heat insulation              | 32°C                      |
| door         | 1      | 1.1m×2m               | Partitions | Constant heat density       |                           |
| personnel    | 8      | 1.73m×0.3m×0.2m       | Persons    |                             |                           |
| Computer     | 8      | 0.4m×0.25m×0.2m       | Blocks     | Constant heat flux          | 1met                      |
| Fluorescent lamp | 6   | 1.2m×0.15m×0.2m       | Blocks     | Constant heat flux          | 150 W / station           |
| Cabinet      | 9      | 0.9m×1.85m×0.4m       | Blocks     | Heat insulation             | 40W / light               |
|              |        | 0.55m×1.5m×0.6m       |            |                             |                           |
| A partition  | 16     | 1.8m×1.1m             | Partitions | Heat insulation             |                           |

The south wall of the room is an external wall, considering the effects of solar radiation. The indoor airflow was simulated when the air supply angle is 0°, the upward angle is 45° and the upward angle is 60°. In these three cases, outlet speed is 4.2 m/s, air temperature is 9.3°C and relative humidity is 87%.

3. Analysis of numerical simulation results
The air outlet has a cross section of 0.22 m×0.46 m and an average height of 1.7 m. The average air velocity is 4.3 m/s, the temperature is 9.3°C and the relative humidity is 87%. When the shutters are at the 0, 45 and 60 degree angles, the temperature distribution and flow distribution are selected at the cross sections which is in accord with the following: Y=0.1 m (the height of ankle), Y=1.1 m (the height of the neck when the person sitting), and Y=1.7 m (the height of air conditioner outlets).

In order to facilitate the analysis, the desk number is shown in Figure 2.

3.1 Speed simulation results
Table 2 shows the measured air velocity at the height of 0.1 m and 1.1 m in the room.

| height   | Station(m/s) 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 |
|----------|----------------|---|---|---|---|---|---|---|
| Y=0.1 m  | 0.02           | 0.01 | 0.34 | 0.20 | 0.02 | 0.03 | 0.10 | 0.33 |
| Y=1.1 m  | 0.04           | 0.02 | 0.35 | 0.10 | 0.62 | 0.10 | 0.57 | 0.65 |

It can be seen from Figure 3, 4 that, when the air is blown from a horizontal angle, the speed of the Station 1, 2, 3, 4 and 6 in the staff working area is basically below 0.25 m/s. The air velocity in the ankle (Y=0.1 m) zone at Station 5, 7 and 8 is about 0.25 m/s. But the air velocity in the work area is relatively large, especially at the Station 7 there is a strong sense of wind in the area of the head (Y=1.1 m), closing to 1.1 m/s. The air velocity in the head area of the Station 5 and 8 is smaller than Station 7, which is between 0.5 ~ 0.7 m/s. With the air blown from a horizontal angle, the Station 5, 7 and 8 have a strong sense of wind and it makes people feel uncomfortable.
Figure 5. 45° angle of air supply
Y=0.1 m velocity distribution.

Figure 6. 45° angle of air supply
Y=1.1 m velocity distribution.

We can see that from Figure 5, 6, when blowing air is upwards at 45° angle, the air flow organization in the room has not a big disturbance and the air velocity is well distributed with the staff in the working state of sitting. In addition, the air velocity of the ankle and head area is basically below 0.3 m/s. Because of the upward air supply, the upper part of Station 5~8 has higher air velocity, but it has no effect on the lower working area.

Figure 7. 60° angle of air supply
Y=0.1 m velocity distribution.

Figure 8. 60° angle of air supply
Y=1.1 m velocity distribution.

As can be seen from Figure 7, 8, when blowing air is upwards at 60° angle, the air flow is mainly concentrated in the area near the front side of the air conditioner, resulting in lower air velocity in the Station 1, 2, 3, 4 and 7 and they are all less than 0.25 m/s. The speed in the ankle area in Station 5, 6, 8 is less than 0.2 m/s. But the air velocity in the head area is higher than 0.3 m/s and near 0.4 m/s. In these areas, there's a slight blow on the head.

3.2 Temperature simulation results
Figure 9. Horizontal angle of air supply
Y=0.1 m temperature distribution.

Figure 10. Horizontal angle of air supply
Y=1.1 m temperature distribution.

Table 3. The table of temperature when the shutters are at the horizontal angle (Y= 0.1 m, 1.1 m)

| Station(°C) | 1  | 2  | 3  | 4  | 5  | 6  | 7  | 8  |
|------------|----|----|----|----|----|----|----|----|
| Y=0.1 m   | 24.4| 25.0| 24.9| 25.0| 21.8| 23.9| 21.6| 21.1|
| Y=1.1 m   | 24.3| 24.8| 24.8| 25.0| 21.9| 24.0| 21.3| 22.9|

From Figure 9 and Figure 10, it can be concluded that when the air is blown from a horizontal angle, the temperature near the ankle is about 22°C and that of the head area is about 21°C in Station 5, 7, 8. The temperature of other stations is basically maintained at 24 ~ 25°C. Station 1 and Station 2 are near the corner and the temperature will be slightly higher than other stations. Table 3 shows the measured temperature at the height of 0.1 m and 1.1 m at the horizontal air supply angle.

Figure 11. 45° angle of air supply
Y = 0.1 temperature distribution.

Figure 12. 45° angle of air supply
Y = 1.1 temperature distribution.

It can be seen from Figure 11 and 12 that, when the air is blown upward at the angle of 45°, the temperature at the ankle of the Station 3, 4 and 7 is between 23°C and 24°C, and that of the head area is about 22°C. The ankle temperature of the other stations varies is between 24.5 and 25.5°C, and that of the head area is about 24°C. Compared with the horizontal angle, the corresponding temperature of indoor working area is a little higher, but in the range of thermal comfort.
From Figure 13 and Figure 14, when the air is blown upward at the angle of 60°, it is found that the temperature in the room is generally high, and the ankle temperature is about 26°C. Because of the sinking of cold air on the side of Station 7 and 8, the temperature is a little lower at about 25°C. When the person sits quietly, the temperature in the head area is between 24.5°C and 25.5°C. The air flow is easy to become poor in the Station 1 and 2 with the highest temperature.

3.3 Best scheme
According to the analysis of the measured data and the simulated data, it is found that the thermal comfort of each station in the room is better when the air is blown upward at the angle of 45°. The working area, the ankle area and the head area will not have the strong wind sense and the temperature distribution is better. The ventilation efficiency in the room is not the best scheme, but it is also good. In summary, without changing the present layout of the room, the indoor thermal comfort can be guaranteed only by adjusting the ventilator shutters of the air conditioning to 45° upward.

4. Air distribution and energy saving

| No. | Possible reasons |
|-----|-----------------|
| 1   | The number of air supply outlet is too small and does not match the density of working desk. |
| 2   | The position of air supply outlet deviates from the working desk and is far away from the working desk. |
| 3   | Air supply outlet type is not suitable. |
| 4   | Indoor air conditioners are split air conditioners and cabinets. |

In order to ensure the thermal comfort of the indoor air conditioning environment, it is necessary to carry out the detailed analysis and design of the indoor air flow organization to ensure the uniformity of the indoor air conditioning temperature and air velocity, especially for the high person density of the office building. Table 4 analyzes the causes of bad thermal comfort of indoor air conditioning.

The unreasonable airflow organization in the air conditioning room will not only affect the thermal comfort and working efficiency of the indoor environment, but also cause select excess large capacity of the air conditioning equipment and increase the operating cost of energy consumption, directly affecting the building energy saving. Table 5 is a comprehensive analysis of the optimization of indoor air distribution organization.
Table 5. Analysis of indoor air distribution optimization

| No. | Optimization item |
|-----|-------------------|
| 1   | Thermal performance of envelope structure |
| 2   | Position of the working desk (The distance from air conditioner outlets and from outside windows, etc.) |
| 3   | Number of the working desk and personnel density |
| 4   | Kind of air supply outlet |
| 5   | Number of air supply outlet and its layout |
| 6   | Indoor temperature and air velocity distribution |
| 7   | Capacity selection of terminal equipment |
| 8   | Energy-saving operation of terminal equipment |

5. Conclusion
In this paper, the three-dimensional numerical simulation of the thermal environment in the office was carried out by using Airpak software in three air supply angles (0°, 45° and 60°). Through analysis of the simulation results about the velocity distribution and the temperature distribution in the indoor air flow under the three operating conditions, it is found that the thermal comfort of the room is the best in the case of the upward air supply of 45° angle. The optimization of air conditioners should not only consider thermal comfort, but also reduce energy consumption of air conditioners to achieve building energy efficiency.

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