Effects of Different Air distributions on the Thermal Environment in the Office

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Abstract. Three kinds of air distribution, including “upper supply and top return”, “upper supply and lower return” and displacement ventilation, are researched in an office building by Fluent simulation software, the effect of the air distribution to the indoor environment can be obtained by analyzing the temperature and velocity distribution. Three physical models (10×20×2.75, width×length×height, unit: m) with different air distribution are established in the research, the temperature field and velocity field are obtained by simulation. The results show that it is beneficial to creating a uniform temperature field and weakening the thermal discomfort caused by draught when the “upper supply and lower return” mode is applied in the office. However, the air vents in the lower part of the room need to be kept clean, otherwise the indoor air quality will be deteriorated, therefore, the selection of air distribution will lead to differences in the initial structure and economy.

1. Introduction
With the development of society and economy, the way people live and work has also changed. For office workers, most of the day is spent in the office [1]. Compared with other buildings, office buildings are more airtight, have higher personnel density, and lower mobility [2]. Therefore, indoor thermal environments require not only matching air conditioning systems, but also good air distribution to maintain the uniformity of the indoor thermal environment, while ensuring the indoor air quality [3]. In terms of indoor air quality [4], there are many electronic devices in office buildings, such as computers and printers. When these devices are running, they will release harmful gases, endanger human health, and reduce work efficiency [5]. In addition, pollutants emitted by the human body into the room through breathing metabolism and harmful gases [6] emitted by interior decoration materials will cause the indoor air quality to decline. Therefore, a reasonable air distribution is required to help exhaust harmful particles and gases, and improve indoor air quality. In terms of indoor thermal comfort, first of all, a reasonable supply air temperature must be ensured. Secondly, the fresh air sent into the room and the distribution of the treated air in the room are closely related to the air distribution [7], so the indoor thermal comfort also requires a reasonable air distribution.

Air distribution [8], in a narrow sense, is the difference in the form of air supply and return caused by the arrangement of air outlets, that is, the form of air distribution. In a broad sense, it refers to the distribution of indoor airflow created by the arrangement of supply and return air outlets and the supply air calculated parameters. The air distribution is designed to satisfy the uniformity and stability of temperature and humidity in air-conditioned areas, ensure indoor air quality, and improve human comfort. At present, the air distribution forms that can be used in office buildings include up to up, up to down and displacement ventilation. In this paper, Fluent software is used to simulate the indoor
environment of the above three air distribution forms, and the effect of the three air distribution forms on the indoor environment is evaluated through the analysis of the simulation results.

2. Model Building

2.1. Physical Model Building
In this paper, an office in a Xiamen office building is used as the research object, and a $10 \times 20 \times 2.75$ (width $\times$ length $\times$ height, unit: m) room model is established. A ceiling is added to the two air distributions for side air outlets layout, physical model and air supply & return air are shown in figures 1-3. The locations and dimensions of the air outlets are listed as followings.

![Figure 1. Schematic of the upper supply and top return air outlets.](image1)

![Figure 2. Schematic of the upper supply and lower return air outlets.](image2)

![Figure 3. Schematic of the displacement ventilation air outlets.](image3)

2.2. Mathematical Model Building
The indoor airflow is turbulent, so the k-ε two-equation model is used for the calculation. The model calculation includes viscous heat, buoyancy and compressibility options and it can obtain higher accuracy results in turbulent flow calculations with high Reynolds. The model governing equations
include continuity equations, momentum equations, energy equations, k equations and ε equations. Indoor air is regarded as incompressible fluid, and it is a steady flow without external fluid interference.

Continuity equation:

$$\frac{\partial u_i}{\partial x_i} = 0$$  \hspace{1cm} (1)

Momentum equations:

$$\frac{\partial}{\partial t}(\rho u_i) + \frac{\partial}{\partial x_j}(\rho u_i u_j) + \frac{\partial p}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_i} + \rho g_i + F_i$$  \hspace{1cm} (2)

Turbulent kinetic energy k equation:

$$\frac{\partial (p k)}{\partial t} + \frac{\partial (p k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_j} \right] + \mu_t \frac{\partial u_i}{\partial x_j} + \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right) - \rho \varepsilon$$  \hspace{1cm} (3)

Turbulent kinetic energy dissipation rate ε equation:

$$\frac{\partial (p e)}{\partial t} + \frac{\partial (p u_i e)}{\partial x_i} = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu_t}{\sigma_e} \right) \frac{\partial e}{\partial x_j} \right] + \frac{C_{1e} \varepsilon}{k} \frac{\partial u_i}{\partial x_j} \frac{\partial u_j}{\partial x_i} + \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - C_{2e} \rho \frac{\varepsilon^3}{k}$$  \hspace{1cm} (4)

where $u_i$—direction velocity; $\rho$—air density, kg/m$^3$; $P$—static pressure, Pa; $\tau_{ij}$—stress tensor, $F_i$—heat source term; $\mu$—kinematic viscosity, Pa/s; $k_{eff}$—effective thermal conductivity; $J_i^f$—diffusion flow of component j; $S_h$—other heat source terms.

2.3. Boundary Condition Settings

Each room in this article is set to be airtight. The size of the air outlet is 1200×200 (unit: mm), the boundary condition type is set to velocity-inlet, the return air outlet is 1000×200 (unit: mm), and the boundary condition type is set to out-flow. Calculated by air distribution check, the upper supply air velocity is 2.5 m/s, the displacement ventilation supply air velocity is 0.3 m/s, and the supply air temperature is 20 °C. For example, to format.

3. Analysis of Simulation Results

The boundary conditions are set according to the determined operating conditions parameters, and simulation is performed using fluent software to obtain the temperature field and velocity field formed by each air distribution. The simulation results are analyzed from three aspects: temperature field uniformity, velocity field strengths and weaknesses, and “draught” to compare the advantages and disadvantages of the three types of air distribution, and evaluate the indoor environment it has formed.

3.1. Temperature Field Uniformity

One of the purposes of the air distribution check calculation is to enable the indoor formation of a uniform and stable temperature field, especially to avoid a large vertical temperature gradient. Therefore, the central section along the direction of the air outlet is taken to evaluate the uniformity of the temperature field, as shown in figures 4-6. Comparing the temperature distribution diagrams of the longitudinal cross sections of the three air distributions, the temperature distributions of the upper supply and lower return are more uniform, and there is basically no temperature stratification in the main activity area of the person. The temperature stratification and thermal vortex area are more obvious, so the uniformity of the temperature field formed by the upper supply and the lower return air distribution is better than the displacement airflow and the upper supply and return air distribution.
Figure 4. \( y = 2.5 \) m section temperature distribution of upper supply and top return.

Figure 5. \( y = 2.5 \) m section temperature distribution of upper supply and lower return.

Figure 6. \( y = 2.5 \) m section temperature distribution of displacement ventilation.

3.2. “Draught” Analysis
The most probable cause of thermal discomfort in air-conditioning rooms is the “draught”, which is mainly due to the local thermal discomfort caused by air temperature and wind velocity. This paper uses the effective blowing temperature in ASHRAE to determine the strength of the “draught”, defined as:

\[
\theta = (t_x - t_r) - 7.8(v_x - 0.15)
\]

where \( t_x, t_r \) —— the temperature at a certain place in the room, the average indoor temperature, \(^\circ\)C; 
\( v_x \) —— the wind velocity at a certain place in the room, m/s.

For the office, when the effective blowing temperature is between \(-1.7\)~\(-1.1\) \(^\circ\)C and the velocity is less than 0.35 m/s, most people feel comfortable. For the entire office area, the air distribution characteristic index ADPI can be used to judge, defined as:

\[
ADPI = \frac{\text{number of test points} \ (-1.7<\theta<1.1)}{\text{Total number of test points}} \times 100\%
\]

The definition of the effective blowing temperature indicates that it is related to the indoor temperature and wind velocity. Therefore, the temperature distribution and velocity distribution of the cross section of the head in the sitting position are selected to calculate the “draught” of the three air distributions. Figures 7-9 are cross-sectional views of three air distributions at a height of 1.2m. By extracting the temperature and velocity data of this section, the ADPI of each of the three air distributions can be calculated.

According to calculations, there are 3037 grids with an effective blowing temperature between \(-1.7\) and 1.1, and the total number of grids is 3321. The ADPI of the upper supply and top return is 90.33%. There are 3197 grids with an effective blowing temperature between \(-1.7\)~\(-1.1\), and the total number of grids is 3444. The ADPI of the upper supply and lower return is 92.65%. There are 2807 grids in between, and the total number of grids is 3457. The ADPI sent back is 81.2%. By observing the velocity distribution diagram, although the velocity distribution of displacement ventilation is mostly
in the order of 0.01 m/s, the overall comfort is weaker than the other two air distributions due to uneven temperature distribution. In summary, the “draught” caused by the air distribution that is sent up and down is the weakest when considering the temperature distribution and wind velocity.

![Temperature Distribution](image1.png)
(a) $z = 1.2$ m section temperature distribution.

![Velocity Distribution](image2.png)
(b) $z = 1.2$ m section velocity distribution.

**Figure 7.** Upper supply and top return air distribution.

![Velocity Distribution](image3.png)

**Figure 8.** Upper supply and lower return air distribution.

![Velocity Distribution](image4.png)

**Figure 9.** Displacement ventilation air distribution.

### 3.3. Velocity Field Analysis
When designing the air distribution, the occurrence of vortexes in the indoor airflow should be minimized. One is that the vortex will cause heat retention and affect the indoor air temperature field. The other is that the existence of the vortex is bad to the indoor airflow and the discharge of pollutants. Therefore, this paper intercepts three kinds of velocity vector diagrams at $x = 5$ m. By observing the direction of airflow, make a certain judgment on the pros and cons of the indoor velocity field, figures 10-12 show the vector diagrams of the indoor velocity fields of the three air distributions.

From the perspective of the velocity, the displacement ventilation velocity is one order of magnitude less than the two others, and the velocity distribution is more uniform. In contrast, the velocity distribution of the others is uneven, the wind velocity near the air outlet is relatively large, and the velocity in the middle of the room is small. From the point of view of airflow distribution, there are obvious vortices in the upper supply & top return and upper supply & lower return, while
there are almost no obvious vortices in the displacement ventilation, and the overall direction of the airflow is upward. It can be seen that displacement ventilation is less likely to form vortices, and the ability to ventilate and discharge pollutants is stronger in the three air distributions.

Figure 10. Velocity vector distribution of upper supply and top return air distribution.

Figure 11. Velocity vector distribution of upper supply and lower return air distribution.

Figure 12. Displacement ventilation air distribution.

4. Conclusion
In this paper, a large-scale office model is used to simulate and analyze the temperature field and velocity field formed by the three air distributions: upper supply-top return, upper supply-lower return, and displacement ventilation. The results show that when the air distribution is sent upper supply and lower return, the indoor temperature distribution is more uniform, and it is not easy to cause a “draught”. It is worth noting that both upper supply-lower return and displacement ventilation require air vents in the lower part of the indoor space. The air distribution is more complicated and the air vents in the lower part of the room need to be kept clean, otherwise the indoor air quality will be deteriorated. The air distribution form can meet the requirements of the air outlet only by setting the ceiling. Therefore, the selection of air distribution will lead to differences in the initial structure and economy. Therefore, in actual engineering applications, the appropriate air distribution should be selected according to the specific economic conditions of the project and the requirements of the indoor environment.

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