A Brand-New Composite Air Supply Scheme for Tall and Square-Built Buildings with Different Air Distribution Variations

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Abstract. The composite air supply for tall space buildings has always grabbed the researchers’ attention. Tall and square-built spaces generally have more complex building structures, along with challenges such as high system energy consumption, poor sewage disposal efficiency, and difficulty in heat dissipation. In addition, tall and square-built space buildings will have a greater impact on the flow of indoor airflow with respect to the air inlet/outlet selection, layout position, and spray angle. Therefore, in order to choose a more suitable plan and create a more reasonable airflow organization form, we use CFD numerical simulation method to simulate the airflow organization of a tall and open-duplex-structured factory in mainland, China. By setting different air supply parameters and air supplier column parameters, the composite air supply scheme combining the tuyere type and the air supplier column type is evaluated respectively. The experimental results show the feasibility and innovation of this scheme to increase the exhaust air volume, reduce energy consumption, and improve the heating effect in tall and square-built space buildings, and also provide a stereotype for the future application of examples on air distribution in similar buildings.

1. Introduction
With the development of commerce, more and more large-space conference halls are set up in commercial office buildings. Due to the “chimney effect” of air supply, large-space places are often affected by factors such as nozzle angle, airflow range, and tuyere position in winter. As a result, the air supply effect is not as expected, and the indoor temperature cannot meet the design requirements. Initially, the test of airflow organization was mainly completed by smoke generation test. The flow velocity of the smoke can be used to objectively judge the size and direction of the flow velocity. However, this type of test is greatly affected by subjective factors. Produce a certain degree of interference. In this regard, before the start of large-scale projects, airflow predictions are mainly carried out by simulation methods [1-3] to discover various flow problems that may occur after the completion of indoor construction, but due to cost, technology and Due to the constraints of construction period and other factors, most small and medium-sized projects cannot simulate and analyze indoor airflow in the early stage of construction.

The existing air supply modes in high and large spaces mainly include upper air supply, lower air supply, side air supply and a combination of multiple air supply methods [4]. Compared with a single air supply method, multiple airflow organization methods are used together. The composite air supply form is easier to meet the energy-saving and economic operation requirements of tall and large space
public buildings. The composite air supply method can adapt to the different requirements of each area in the large space, and it is relatively easy to achieve the best air organization effect in the room. Therefore, in the tall space of the sample atrium in this article, a composite air supply method combining floor and air supply columns is used to meet the load demand of the air conditioning season. In the transitional season, the air conditioning system in this area is disabled, and natural wind is selected as the natural cooling source to meet the load demand in the atrium by natural ventilation.

In accordance with the requirements of the HVAC design specification, the indoor temperature of the central air-conditioning system in modern commercial public areas and large places should not be lower than 16°C in winter. However, because large conference halls and banquet halls have large areas, frequent flow of people, and long air outlets, and the door cannot be kept normally closed, which results in a large amount of indoor heat loss, the actual heating capacity for such areas should be higher than other public places. Since the ceiling height of tall buildings exceeds 10m, if the diffuser is used for air supply, although the air flow is evenly distributed, the air supply direction will not be concentrated, and there is a large amount of airflow dissipation, shortening the range, which is not conducive to vertical air supply at high altitude. At the same time, in the state of air-conditioning and heating, once the warm air flow has a significant floating effect (that is, the "chimney effect"), it will not be able to send the air flow to the ground.

On the other hand, tall buildings have the advantages of saving land resources and low noise pollution, and they have developed rapidly in China. However, there are also problems such as difficulty in operation and maintenance and high potential safety hazards [5-8]. The underground fully sealed design, the environment is relatively closed, the sewage treatment process is likely to cause the accumulation of malodorous gas and cannot be eliminated. The main components of malodorous gas are H2S and NH3. The odor threshold is low and the toxicity is high. If not properly managed, it will seriously affect the health of the staff [9, 10]. Airflow organization is very important in improving the ambient air quality in underground spaces, and proper airflow organization is also an important means for sewage and deodorization.

2. Model Construction and Validation

2.1. Model Construction

Figure 1(a) is a schematic diagram of a tall building before renovation, with length×width×height of 100.5 m×20.5 m×5.0 m. The side wall of the machine room is equipped with 3 air outlets with a length of 0.5 m × 0.4 m and a height of 2.3 m from the ground. They are located in the middle of the wall. Before the renovation, the building was only equipped with air exhaust and no air supply system. There is an interlayer isolation in the middle, as shown in figure 1(b).

![Figure 1. Model of a tall and square-built building before reconstruction.](image)
2.2. Model Computation
The computational domain of the model is relatively simple and the hexahedral mesh with high computational accuracy is adopted [11, 12]. The grid is divided into 80×100, 150×100, 270×100, 400×100, 1 000×10- and 2000 ×100. The wind speed and temperature at the door of the dewaterer can be seen from the results that the calculated results tend to be stable when the number of grids reaches 500×104, so the number of model grids is 500×104 [13]. RNG model in Fluent can achieve good results in indoor air flow simulation [14]. RNG model is adopted in this study to predict the air distribution. At the same time, involving the diffusion of malodorous gases, the Species Transport model was adopted.

2.3. Design of Air Supply Parameters of Air Supplier Column
The air supply column bears the cooling load of indoor human body, equipment and lighting, Q =40 kW, and the air supply volume L= 40000 m³/h. Atrium corners set 4 pillar of large air supply, each pillar of air supply for 10000 m³/h air volume, the wind column with 3 surface air inlet alongside highly stratified (2 and 4 m respectively opening inlet) way to meet the needs of air conditioning far, including air column 2 m of the nozzle undertakes air volume 10000 m³/h, 4 m at the nozzle undertakes airflow 13000 m³/h, spherical vents parameter calculation results are shown in table 1.

| Inlet Location | Air Volume m³/h | Nozzle diameter / mm | Air spend m/s |
|----------------|-----------------|----------------------|--------------|
| 2m spot        | 10000           | 200                  | 6.3          |
| 4m spot        | 13000           | 220                  | 7.2          |

2.4. Boundary Conditions
According to the field measured data and the operation characteristics of the machine room, the boundary conditions are set as follows: 1) Constant air volume of the exhaust outlet and exhaust air. According to the air volume and exhaust area, the wind speed can be obtained and set as the speed. 2) The door is always open, and the air is automatically filled and set as pressure inlet; 3) The hopper mouth is the main source of odor and heat, and is set as the source phase. According to the measured data, the heat source strength is 2,800 W, and the odd source strength is 10.28 mg /s. 4) Ignore the heat transfer of the wall and set the wall as an adiabatic wall.

2.5. Model Validation
The sampling point height (Z) of the taste concentration in the building with an outdoor temperature of 30 °C is 0.5, 1.5, 2.0 and 3.0 m respectively, divided into group 1, group 2, group 3 and group 4. The measurement of malodorous gas NH₃ adopts pump suction NH₃ gas detector. In order to verify the accuracy of the numerical simulation, the measured NH₃ concentration was compared with the simulated data, as shown in table 2. It can be seen from figure 2 that the measured values of measuring points 1 and 2 near the hopper mouth are higher than the simulated values, and the measured values of measuring points 4 and 5 at the doorway are lower than the simulated values. This is mainly related to the simplification of the geometric model during numerical simulation. Overall, the actual measurement is close to the CFD simulation result, with an average relative error of 19.1%. Errors caused by simplification of measuring instruments and models are inevitable. The comparison results show that the RNGκ-ε model and Species Transport model can reasonably predict the distribution of indoor flow.
Figure 2. Air supply temperature (a) and velocity (b) cloud map.

Table 2. Air Supplier Column Parameters.

| Group | Air-in | Air-out | Volume of air-in | Volume of air-out |
|-------|--------|---------|-----------------|------------------|
| 1-1   | Top    | Bottom  | 0               | 10040            |
| 1-2   | Top    | Middle  | 5540            | 10040            |
| 1-3   | Top    | Bottom  | 5540            | 10040            |
| 2-1   | Top    | Middle  | 6900            | 10040            |
| 2-2   | Top    | Bottom  | 6900            | 10040            |
| 2-3   | Top    | Middle  | 6900            | 10040            |
| 2-4   | Bottom | Middle  | 6900            | 10040            |
| 3-1   | Top    | Bottom  | 3150            | 8100             |
| 3-2   | Middle | Bottom  | 3150            | 8100             |

3. Numerical Stimulation

3.1. Temperature Graph
Considering the influence of solar radiation on the glass curtain wall, a radiation model is added, so the temperature is slightly higher near the curtain wall. The floor air supply temperature is 20°C. It can be seen from figure 2(a) that with the diffusion of the airflow, the temperature to the human ankle is about 23.4°C, and the average indoor temperature is 25.5°C. The overall indoor temperature field is good; the through space is used as a return air outlet. Since this location is not fully air-conditioned, the average return air temperature is relatively high, about 29°C, which is significantly different from the indoor temperature.

3.2. Velocity Graph
It can be seen from figure 2(b) that when the floor air supply is at Z=0 m, the air supply speed is 1.40 m/s, and the Vair supply speed is less than 0.1 m/s when it reaches the position of the human ankle. At the height of the human body Z=1.7 m (about the position of the human head), the comprehensive influence of the floor and the air supply column is weak. The wind speed is less than 0.2 m/s, and the wind speed is within a reasonable range. The penetrating space flows out.

3.3. Air Distribution of Atrium Supply Column
It can be seen from figure 3 (a) that there are obvious vertical temperature gradients and thermal stratification in the atrium. The indoor temperature of the stratification height below 2 m is 21-26 °C, which meets the design requirements. It can be seen intuitively from figure 3 (b) that the air supply...
column delivers air on three sides at Z=4 m, and the air supply from the air supply column gradually attenuates to the pedestrian height area, and the airflow organization is good. Therefore, the combination of the floor and the air supply column can make the indoor air distribution more uniform.

(a) (b)

Figure 3. Temperature stratification (a) and velocity (b) cloud diagram of atrium space.

3.4. Air Distribution Evaluation
In order to evaluate the airflow organization in the atrium when the floor and the air supply column are combined with air supply, 12 measuring points at Z=1.5 m are selected to measure the temperature and velocity distribution of each point, and analyze the uneven coefficient and air distribution characteristic indexes. The specific values of the non-uniformity coefficient and the air distribution characteristic index (ADPI) can be obtained by calculating the selected measuring points. The calculation results are shown in Table 3.

Table 3. Evaluation results of air distribution.

| Velocity Parameter | Temperature Parameter | ADPI   |
|--------------------|-----------------------|--------|
| 1.02               | 1.0                   | 93.8%  |

Both Velocity and temperature parameters are dimensionless numbers. The smaller the value of the two, the better the uniformity of the airflow distribution, so the obtained airflow distribution uniformity is better; ADPI=93.8%>80%, indicating that the temperature and velocity distribution is relatively uniform the indoor air distribution characteristics are good and meet the design requirements [9]. The results of CFD numerical simulation and airflow organization evaluation show that in summer under the combined air supply form of the floor and the air supply column, both the temperature field and the velocity field can meet the human body heat Comfort requirements.

3.5. Air Pollution Disposal Evaluation
Evaluation indicators in recent years, domestic and foreign studies have used sewage efficiency to evaluate airflow organization [15-16]. This study uses sewage efficiency ε as an index for evaluating airflow organization.

\[ \varepsilon = \frac{\varphi_R - \varphi_S}{\varphi_P - \varphi_S} \]  

(1)

In the equation: \( \varphi_R \) is the odor volume fraction of the exhaust outlet, \( 10^{-7} \); \( \varphi_P \) is the average odor volume fraction in the machine room, \( 10e^{-7}/\varphi_S \) is the odor volume fraction of the air inlet, the volume fraction of the odor of the infiltration airflow from the door is very small, which can provide a good working environment for the staff, experimental result is shown below table 4.
Table 4. Air Pollution Disposal Result.

| Group | $\varphi_p (10e-7)$ | $\varepsilon$ |
|-------|---------------------|---------------|
| 1-1   | 0.88                | 0.18          |
| 1-2   | 3.12                | 2.86          |
| 1-3   | 3.80                | 2.18          |
| 2-1   | 3.88                | 2.20          |
| 2-2   | 3.91                | 2.31          |
| 2-3   | 3.28                | 1.93          |
| 2-4   | 3.43                | 2.02          |
| 3-1   | 2.56                | 1.43          |
| 3-2   | 2.70                | 1.58          |

4. Air Pollution Disposal Evaluation
The odor concentration in the work area is more important to the safety of workers. Figure 4 shows the influence of seven airflow organizations on the odor concentration in the work area under 2 m in the computer room. It can be seen that the average volume fraction of NH3 in the working area is the largest at $3.0 \times 10^{-7}$ when the lower air supply side and the upper air discharge side of the working condition 2 side. Working condition 6 the average volume fraction of NH3 in the working area under the condition of three-dimensional air supply and middle exhaust is $5.0 \times 10^{-8}$, which is 62.9% lower than the measured data. With the three-dimensional air supply in the middle row mode, the respiratory odor concentration of the staff in the computer room is lower than other airflow organizations. The results show that, considering the health of the staff, using the central exhaust of the three-dimensional air supply, the average odor concentration at the breathing height of the computer room is the lowest, the odor concentration in the work area is the lowest, and the sewage discharge efficiency is the highest, which can provide a better working environment.

Figure 4. Concentration of toxic gas at certain height.

4.1. Evaluation of Heating Effect of Tall and Square-Built Buildings
We came up with three preliminary solutions to the problem. The first two solutions both have defects: 1) Change the form of the tuyere to the nozzle tuyere, increase the wind speed of the end tuyere by reducing the ventilation section, and enhance the hot air flow, so that the hot air can reach the bottom of the room and perform forced convection heat exchange with the cold air below the room. Because the ceiling has been completed at the site, if the tuyere form is changed, a large number of nozzles need to be repurchased, and repeated disassembly and assembly will also cause a significant increase in costs. Secondly, the multifunctional hall is a high-altitude area with a relatively high risk factor for
operations. At the same time, the increase of the air supply wind speed will often lead to an increase in the noise of the tuyere, which does not meet the use requirements of places such as large lecture halls. 2) The form of the air outlet remains unchanged, the position of the air outlet is changed, and the form of ceiling air supply is changed to wall side air supply. The air outlet is set 3m above the ground, and the vertical path of the air supply is shortened to increase the heat exchange effect. Part of the branch pipe led by the air supply main pipe is turned down along the indoor wall, and the air supply port is set at a distance of 4m from the ground. Although this solution can send hot air to the bottom, due to the limitations of the building structure and other pipelines, it is impossible to draw all the air outlets down, which makes the heat sent to the bottom limited. At the same time, due to the setting of air outlets on both sides of the wall in this solution, the comfort of the audience directly on both sides of the wall may decrease due to the proximity of the air outlet.

We adopt the last solution: change the position of the return air outlet, change the centralized return air from the ceiling to return air at the bottom of the hall, speed up the circulation of cold air in the hall, and improve the heating effect in the hall. Change the ceiling centralized return air (send up and return) form to bottom return air (send up and return to the bottom) form, set the return air outlet at 0.8m from the ground, and change the airflow organization direction in the multifunctional hall to make winter heating more effective. When hot air is supplied, the return air vent below can accelerate the flow of cold air on the ground, thereby improving the heating effect in the hall. At the same time, this scheme has low difficulty in construction and transformation, low risk, greatly reduced transformation cost and construction period, and is more implementable than the other two schemes.

From the data in table 5, it can be concluded that after renovation with reference to Scheme 3, the multi-function hall can reach the temperature value (above 20°C) desired by the owner within 1 hour of the air conditioner being turned on, and can basically maintain a temperature slightly higher than 24°C within 2 hours. Therefore, according to solution, changing only the position of the return air outlet to affect the air flow without increasing the heating capacity [17], the temperature adjustment effect is significant.

Table 5. Temperature data after reconstruction.

| Measuring Spot Number | Temperature After 1 hour | Temperature After 2 hours |
|-----------------------|--------------------------|----------------------------|
| 1                     | 22.4                     | 24.9                       |
| 2                     | 21.9                     | 24.5                       |
| 3                     | 22.3                     | 24.9                       |
| 4                     | 22.0                     | 24.8                       |

5. Conclusion

This paper focuses on the design and research of the airflow organization of a tall and square-built building system. Aiming at the tall space in the atrium, combining the calculated parameters, using the CFD numerical simulation method to simulate the indoor thermal environment, and analyzing the combination of the floor and the air supply column in the air conditioning season. Whether the composite air supply method and the natural ventilation method in the transition season can meet the indoor heat demand. At the same time, the paper discusses that a large space project can optimize the air distribution of air conditioning in winter under more economical conditions by adjusting the position of the return air outlet, and change the flow of warm air, thereby improving the heating effect. The conclusion drawn in this paper is that, for tall spaces, the ventilation method of the upper supply and the lower return is more reasonable, which can increase the airflow along the way and effectively overcome the influence of the "chimney benefit" of the winter air conditioning system. Finally, in the form of three-dimensional air supply, the exhaust air volume has a greater impact on the efficiency of sewage discharge and the concentration of odor, and the effect on the control of the concentration of odor is obvious. It is possible to achieve the purpose of energy saving while improving the malodorous environment by appropriately adjusting the air supply and exhaust volume.
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