Simulation study on Air Outlet of Data Center

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Abstract. How to reduce the amount of wasted cooling in corridors and gaps is a problem in data center air conditioning design. Modeling the data center airflow data and simulating the temperature distribution are the prerequisites and key points to solve this problem. This paper uses the optimal idea to establish a mathematical model to simulate the location of the air conditioning vent. Determine the layout of the computer cabinet based on the analysis of the internal and external environment of the computer cabinet. The external environment analysis is mainly the analysis of several directions: According to the CFD simulation and simulation, the wind speed and tuyere arrangement of the air supply port are compared and the optimal wind speed of the air supply port is obtained. For the problem of the ceiling height and the spacing of the upper air outlet, discuss the method of determining the air supply spacing on the air duct so that the upper air supply can cover all the air inlets of the cabinet to achieve the most reasonable air supply flow. For the numerical simulation and optimization of the airflow organization in the equipment room, it is easy to know that the farther away from the air conditioner, the higher the temperature is relative to the air conditioner, and the wind speed far from the air conditioner is relatively large, so the temperature in the distance is higher. Also, because the hot aisle has no ventilation slots, its temperature must be higher than the cold aisle. Therefore, the temperature in the hot aisle is higher than the ground and the air conditioner is far away. According to the airflow dynamic equation and the K-ε turbulence model equation, the Fluent software is used, and combined with the data given in the data center room, the airflow data is simulated. Finally, the best solution for setting the position of the air conditioning air outlet is given.

1. The Description of the Problem
Among the many electricity costs in the data center, the electricity consumption of air conditioners accounts for a considerable proportion. Looking for information, only the precision air conditioners account for a large proportion of the electricity consumption of air conditioners in the data center. According to the survey, only the operation of precision air conditioners consumes more than 50% of the total electricity costs of the computer room. Therefore, rational design of the air conditioning system in the data center is of great significance for reducing the PUE of the data center computer room.

In the equipment room, due to factors such as unreasonable design, the airflow in the equipment room will be unreasonable and unobstructed, resulting in problems such as local hot spots and low energy utilization rate of the equipment room. Therefore, it is not only necessary to rationally design the air conditioning system of the machine room, but also to propose an airflow organization optimization design plan, and then to find a suitable air conditioning position under the fixed machine equipment
layout, which has a great effect on energy saving and emission reduction of the data center computer room.

2. Establishment and solution of the model
First of all, according to the layout of the computer cabinet in the room, we design the problem change simulation of the interior of the cabinet and the interior environment of the cabinet. Before the design simulation, we have a basic understanding of the basic parameters, corresponding arrangement and heating mode of various cabinets. After the equipment enters the operation state, it will radiate heat outwards. If there is no effect of wind, the heat will only be diffused by the heat expansion model (air heat transfer model). Therefore, we can simulate the space approximate distribution state of temperature in the whole machine room.

2.1. Determination of computer cabinet layout
First of all, we will determine the layout of cabinets and heat capacity in the data center room. Only these can we find the optimal location and spacing of the cold air port, the optimal location of heat capacity and other room parameters. This group takes the computer room layout of a data center in Tai'an City as an example to find the optimal layout scheme.

2.2. External environment of computer cabinet
In order to better determine the layout of the hot container and cold air outlet in the data center room, we need to consider not only the impact of the internal environment of the computer cabinet on the utilization rate of cold air, but also the external environment of the computer cabinet. Therefore, members of this group from the ceiling (i.e. the height of the cold air outlet) to the cabinet, the typical heat dissipation of the computer, and the air outlet of the cold air More in-depth research has been carried out on the wind speed and hot air exhaust rate, the heating rate of the cabinet, the numerical simulation and optimization of the air distribution in the machine room, etc.

2.2.1. Determination method of ceiling height and upper air supply outlet spacing
As a result of the comparative study on the upper and lower return modes of the data center power room, the geometric model is simplified, only the cabinet part is reserved, and the simplified model is shown in Figure 2; in the figure, V1 is the air supply outlet, and the height of the air supply outlet is 4.6m; V2 is the air return of the heat capacity.

![Figure 1 Plan of a data center machine room](image)
Because the arrangement of data center cabinets makes the flow field simulation more simple, so the standard k-ε model of two equation model in turbulence model is applied. In order to clarify the exit velocity and boundary problems, the calibration air supply port V1 is set as the velocity inlet boundary, the heat capacity air return port V2 is set as the free boundary, and the other boundary is the wall boundary.

For the air supply and air conditioning system on the machine room, a good air distribution should be able to evenly send the cold air to the air inlet of each communication cabinet, so that the cabinet can completely exchange heat, at the same time, the hot air discharged can quickly return to the air conditioning unit to be processed, forming a heat exchange cycle, so as to ensure the good operation of the communication machine room. The special air conditioner in the machine room has the characteristics of large air volume and small enthalpy difference. Restricted by the space of the machine room, the outlet wind speed of the downward air supply outlet is large, forming turbulent jet. The transverse pulsation of turbulence causes the mass and momentum exchange between the jet and the surrounding medium, and drives the surrounding medium to flow, so that the cross-sectional area of the jet increases along the jet direction. When the distance between the two tuyeres is large, the dead angle area which is hard to reach by air-conditioner will be formed. A good air distribution should ensure a certain distance between air outlets, avoid dead angle of air flow, and eliminate high temperature alarm of communication cabinet. When the air flow from the air supply pipe reaches the air inlet surface of the cabinet, if the air flow section can reach the air inlet covering the communication cabinet, so that it is not in the dead area of the air supply of the air conditioner, the air distribution is considered to be more reasonable. In order to obtain a reasonable air distribution, the following methods are used to calculate the optimal spacing of air supply outlets. When the air supply reaches the air inlet area of the cabinet, the calculation formula of the air flow width D is as follows:

\[ d_s = 6.8 \times (a \times s^{0.147} d_0) \]  

The symbols are explained as follows: \( d_s \): the width of air flow when the air supply reaches the air inlet area of the cabinet (m); \( d_0 \): the diameter of the air outlet (m); for the rectangular air outlet \( d_0 = 1.13 \times A \times B \), A and B are the width and length of the rectangular air outlet respectively. In this paper, A = 350 mm, B = 500 mm; a: the turbulence coefficient of the air outlet, a= 0.16; s: the distance from the air outlet to the upper boundary of the working area of the cabinet (m).

2.2.2. Wind speed of up air supply and exhaust rate of heat capacity
As we all know, accurate cooling is an efficient way to take away heat for cooling of cooling equipment. Therefore, the size, wind speed and location of the air supply outlet have certain influence on the heat dissipation of the power room. According to the calculation of the number of cabinets arranged in the data center, the heat dissipation capacity of the equipment is about 150 kW; the air volume of the terminal air conditioning fan is selected according to the air cooling ratio of 200
As shown in Figure 3, there are 10 air supply outlets V1, and each air supply outlet is regarded as uniform air supply. It can be seen that the air volume of a single air supply outlet is 3000 $m^3/h$. P1 and P2 are observation sections. Fig. 10 observation diagram of transverse and longitudinal section of a data center.

![Figure 3 Observation diagram of transverse and longitudinal section of a data center](image)

According to the known air volume of the air supply outlet V1, the air velocity of the air outlet is selected as: 1.5 $m/s$, 2.0 $m/s$, 2.5 $m/s$ and 3.0 $m/s$ respectively. The corresponding air vent size can be obtained, as shown in Table 1:

### Table 1 Wind speed and size of different air supply outlets

| working condition | Exhaust volume ($m^3/h$) | Wind speed ($m/s$) | Width of tuyere (mm) | Tuyere length (mm) |
|-------------------|--------------------------|-------------------|---------------------|-------------------|
| working condition 1 | 3000                     | 1.49              | 700                 | 800               |
| working condition 2 | 3000                     | 2.08              | 500                 | 800               |
| working condition 3 | 3000                     | 2.6               | 400                 | 800               |
| working condition 4 | 3000                     | 2.98              | 350                 | 800               |

In the actual reconstruction projects of some built data centers, due to the long service life of the terminal air conditioner, the cooling capacity of the air conditioner decreases; the unreasonable air distribution design and other reasons, the cooling capacity of the air conditioner does not meet the cooling needs of the equipment room. At present, the air conditioning transformation of the existing data center often considers the short-circuit effect of air distribution at the air supply and return outlets. When the air distribution of the data center power room is up and down, the closer the air supply outlet and the air return outlet are, the easier it is to make the cold air directly return to the air conditioning cabinet room without heat exchange in the computer room, resulting in a short circuit of the cold air. As described in the model, the influence of the horizontal distance between the first air supply port and the return port on the cold air return is generally considered. According to the above problems, the horizontal distance between the first air supply outlet and the return air outlet is 1.0m, 1.5m, 2.0m and 2.5m respectively for simulation, as shown in Table 2:
Table 2 Horizontal distance between the first air supply outlet and the return air outlet

| working condition | working condition 1 | working condition 2 | working condition 3 | working condition 4 |
|-------------------|--------------------|--------------------|--------------------|--------------------|
| Horizontal distance between the first air supply outlet and the return outlet | 1.0 m | 1.5 m | 2.0 m | 2.5 m |

It can be seen from the comparison of the simulation results of the speed of four working conditions that: under working condition 1, the air supply from the first air supply outlet basically flows back to the air return outlet, resulting in almost complete short circuit of the air flow at the first air supply outlet; under working condition 2, most of the air supply from the first air supply outlet directly flows back, resulting in most of the short circuit of the air supply from the first air supply outlet; under working conditions 3 and 4, only a few of the air supply from the first air supply outlet directly flows back. The short circuit phenomenon of air flow is less.

2.2.3. Numerical simulation and optimization of air distribution in machine room.
The farther away from the air conditioning position, the higher the temperature is relative to the air conditioning position, and the greater the wind speed is relative to the air conditioning distance, so the temperature in the distance is higher. Similarly, because the hot channel has no ventilation slot, its temperature must be higher than the cold channel. Therefore, in the hot channel, the temperature is higher at the place which is far from the ground and the air conditioner. According to the dynamic equation of air flow and K - ε turbulence model equation, using FLUENT software, combined with the data given in the attachment, the numerical simulation of air distribution is carried out.

The three-dimensional N-S equation (control equation of airflow) describing the air flow in the machine room is represented by the following equation:

mass conservation equation:

\[
\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x_i} (\rho \mu_i) = 0
\]

momentum conservation equation:

\[
\frac{\partial (\rho \mu_i)}{\partial t} + \frac{\partial}{\partial x_j} (\rho \mu_i \mu_j) = \frac{\partial}{\partial x_i} \left[ \mu \left( \frac{\partial \mu_i}{\partial x_j} + \frac{\partial \mu_j}{\partial x_i} - \frac{2}{3} \delta_{ij} \frac{\partial \mu_i}{\partial x_i} \right) \right] + \frac{\partial}{\partial x_j} (-\rho \mu_i \mu_j)
\]

energy conservation equation:

\[
\frac{\partial}{\partial t} (\rho \varepsilon) + \frac{\partial}{\partial x_j} (\rho \varepsilon \mu_j) = \frac{\partial}{\partial x_j} \left[ \left( \mu + \frac{\mu}{\sigma} \right) \frac{\partial \varepsilon}{\partial x_j} \right] + G_k + G_b - \rho \varepsilon - Y_m + S_k
\]

Where \( G_k \) is the turbulent kinetic energy generated by laminar velocity gradient; \( G_b \) is the turbulent kinetic energy generated by buoyancy; \( Y_m \) is the wave generated...
by excessive diffusion in compressible turbulence; $C1$, $C2$, $C3$ are the turbulent Prandtl number constants; $\delta k$ is the turbulent Prandtl number (no factor number) of K equation; $\delta \epsilon$ is the turbulent Prandtl number (no factor number) of K equation;

$S_k$, $S$, $\epsilon$, is a custom parameter.

The turbulence velocity is determined by the following formula:

Where $C_\mu$ is a constant.

$$\mu_i = \rho C_\mu \frac{K^2}{\epsilon}$$

The model constants are as follows:

$C_\mu = 0.09, C_{1\epsilon} = 1.44, C_{2\epsilon} = 1.92, \sigma_k = 1.0, \sigma_\epsilon = 1.0$

These constants are derived from experiments, including the basic turbulence of the air.

RNG model equation

$$\frac{\partial}{\partial t} (\rho k) + \frac{\partial}{\partial x_i} (\rho k \mu_i) = \frac{\partial}{\partial x_j} \left( \alpha_k \mu_{\text{eff}} \frac{\partial k}{\partial x_j} \right) + G_k + G_b - \rho \epsilon - Y_M + S_k$$

$$\frac{\partial}{\partial t} (\rho \epsilon) + \frac{\partial}{\partial x_i} (\rho \epsilon \mu_i) = - \frac{\partial}{\partial x_j} \left( \alpha_\epsilon \mu_{\text{eff}} \frac{\partial \epsilon}{\partial x_j} \right) + G_{1\epsilon} \frac{\epsilon}{k} (G_k + C_{3\epsilon} G_b) - C_{2\epsilon} \rho \frac{\epsilon^2}{k} - R_e + S_\epsilon$$

Where, $G_k$ is the turbulent kinetic energy generated by the laminar velocity gradient; $G_b$ is the turbulent kinetic energy generated by the buoyancy; $Y_M$ is the wave generated by the diffusion of the transition in the compressible turbulence; $S_k$ is the constant; $C1$, $C2$, $C3$ is the constant of the turbulent Prandtl number; $\alpha_k$ is the turbulent Prandtl number of the equation.

When gravity and temperature are to appear in the simulation, the K-\(\epsilon\) model in Fluent takes the influence of buoyancy into account in the K equation, and correspondingly also in the equation. The buoyancy is given by the following formula:

$$G_b = \beta g_i \frac{\mu_t}{\rho T} \frac{\partial T}{\partial x_i}$$

PRT is the Prandtl number of turbulent energy;

The component of gravity in the I direction.

For standard and modified K-model with swirl, the default value of $prt$ is 0.85 in RNG model

$$\beta = -1 \frac{1}{\rho} \frac{\partial \rho}{\partial T}$$

$$G_b = -g_i \frac{\mu_t}{\rho \rho T} \frac{\partial \rho}{\partial x_i}$$

It can be seen from the K equation that the turbulent kinetic energy tends to increase in the unstable layer. For the stable layer, buoyancy tends to restrain the turbulence. In Fluent, when gravity and temperature are included, the influence of buoyancy is always included. Of course, the influence of buoyancy on K is relatively clear, but the influence of buoyancy on \(\epsilon\) equation is not very clear. The degree of influence of buoyancy on \(\epsilon\) equation depends on the constant C, which is calculated by the following formula:

$$C_{3\epsilon} = \tanh \left| \frac{\nu}{\mu} \right|$$

Here $V$ is the velocity component of the fluid parallel to gravity and the component perpendicular to gravity. C will be 1. For the layer fluid with the same velocity direction as gravity, for the buoyancy stress layer it is the vertical gravity velocity, and C will become 0.
2.3. Design scheme of air conditioning outlet and exhaust outlet

To get the best solution of air-conditioning outlet, we need to make clear the parameters of a computer room and the cabinet, which is the premise of our research. The following table is the basic data parameters of the machine room studied by this group:

| Table 3 Data parameters of a data center computer room |
|-------------------------------------------------------|
| **Parameter** | **Value** | **Unit** |
| Conditioned size | 1.055m × 0.85m × 1.95m | |
| Return air outlet | 0.9m × 0.6m | |
| Air supply temperature | 17 ℃ | |
| Air supply height of the machine room | 4.6 | |
| Air return port away from the ground | 0.3m | |
| Air supply speed of the air supply outlet | 2.5 m/s | |
| Horizontal distance between air supply outlet and return port | > 2.0m | |
| Air supply jet rectangular | 500 × 350 | |
| Air supply duct distance from air inlet | 0.45 | |
| Design air flow | 2500m³/h | |
| Demand cold air | 17 kW | |
| Cabinet type | New NCR | |
| Cold air vent capacity | 5000m³/h | |

According to the comparative study of the upper and lower air distribution modes in the data center computer room, the following conclusions are drawn through the simulation experiment:

1. The air supply height of the machine room is 4.6; when the air return port is 0.3m away from the ground, the air supply speed of the air supply outlet is 2.5m/s more reasonable.

In order to avoid short circuit of air flow caused by too close horizontal distance between air supply outlet and return air port, it is more reasonable to select air supply outlet and return air port with horizontal distance greater than or equal to 2.0m.

The air supply jet shall cover the air inlet of the whole cabinet. When the air supply jet is 500 × 350 rectangular, if the machine room is a new NCR cabinet, it is suggested that the air supply duct should be 1.7 away from the air inlet; if it is other cabinets, it is suggested that the air temperature of the air duct well should meet the air supply duct's 0.45 away from the air inlet. At this time, reasonable air can be obtained Flow organization. If the size of the air inlet or the height of the air inlet of the cabinet changes, the air inlet area of the large cabinet can be calculated by formula (1) to ensure that the air flow covers the entire air inlet of the cabinet.

3. The evaluation and promotion of the model

3.1. Advantages of the model

1. This model takes into account various aspects when considering the optimal solution of the air outlet spacing. Any other cabinets other than the new NCR cabinet also give more appropriate recommendations.

2. In this model, if the size of the tuyere or the height of the air inlet of the cabinet changes, only the formula needs to be changed to ensure that the cold air covers the entire air inlet of the cabinet.

3. The model is clear, mathematically rigorous, theoretically enhanced, using a large number of mathematical formulas and mathematical software, such as Fluent software, and also uses physics knowledge. Numerical calculation method is used to simulate indoor airflow organization. It is an effective way to analyze the temperature and velocity distribution of the flow field in the room.

4. This model is a modern new green machine room, which solves the heat
distribution problem of the machine room with environmental protection, energy saving and practicability. To ensure the healthy operation of the equipment in the equipment room, it can achieve energy saving and environmental protection, and realize the green machine room. It is in line with the current energy saving and consumption reduction IT field. A big theme.

3.2. Shortcomings of the model
The model requires a large amount of calculation, so it is inconvenient to handle. When using Fluent to solve, it needs to be iterated multiple times to achieve convergence, which is easy to cause errors.

3.3. Model promotion
The model is not only suitable for the distribution of hot and cold passages in the machine room, but also for the distribution of hot and cold passages in the upper and lower machine rooms, and the significance of realizing the green machine room is more significant.

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