Research on Energy Saving of Air Conditioning System in Data Center

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Abstract. With the development of the Internet today, there are more and more small and medium data center computer rooms, the energy consumption of data centers has also become the focus of attention. Air conditioning system is a big energy consumer in data centers, approximately 40% of the total energy consumption of the data center. So reducing the energy consumption of air conditioners has become the top priority of reducing the energy consumption of data centers. This paper studies the air distribution generated by different air-conditioning methods, building a computer room model and uses the simulation software 6sigma to simulate the different air conditioning modes, thereby reducing the energy consumption of the computer room.

1. Introduction
In the same computer room, the airflow organization corresponding to different air supply methods is different. Therefore, the energy consumption of the corresponding computer room is also different[1,2]. Reasonable airflow organization can make full use of the cold airflow of the air conditioner for the heat dissipation of the server in the cabinet, reduce the waste of cold air flow, thereby reducing the energy consumption of the computer room[3,4]. Therefore, in order to more intuitively understand the temperature distribution and air distribution in the computer room under different air supply modes, the most efficient and most applied method is to use software for fluid simulation[5,6].

This paper establishes a model of a small and medium-sized computer room, and uses the data center simulation software 6sigma to simulate and calculate different air supply modes, and finally analyse the simulation results.

2. The establishment of the computer room model
In this part contains the mathematical model and the physical model of the computer room.

2.1. The establishment of the mathematical model of the computer room
The basis of any numerical simulation calculation is the corresponding mathematical model and control equation. On the basis of understanding the physical model of the data center computer room, it is necessary to establish the corresponding mathematical model and control equation.

2.1.1. Mass conservation equation. Since there is no external window in the room, the air tightness is good, and the gas flow in the room must meet the law of conservation of mass. The equations can be written as follows:
\[
\frac{\partial \rho}{\partial t} + \frac{\partial \langle \rho u \rangle}{\partial x} + \frac{\partial \langle \rho v \rangle}{\partial y} + \frac{\partial \langle \rho w \rangle}{\partial z} = 0
\]  
(1)

where \( \rho \) is density, \( t \) is time, \( u, v, w \) is the velocity component of the velocity vector in the X, Y, and Z directions respectively.

2.1.2. Momentum conservation equation.

\[
\frac{\partial \langle \rho u \rangle}{\partial t} + \text{div}(\rho uu) = -\frac{\partial \rho}{\partial x} + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{yx}}{\partial y} + \frac{\partial \tau_{zx}}{\partial z} + F_x
\]  
(2)

\[
\frac{\partial \langle \rho v \rangle}{\partial t} + \text{div}(\rho vu) = -\frac{\partial \rho}{\partial y} + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{zy}}{\partial z} + F_y
\]  
(3)

\[
\frac{\partial \langle \rho w \rangle}{\partial t} + \text{div}(\rho wu) = -\frac{\partial \rho}{\partial z} + \frac{\partial \tau_{xz}}{\partial x} + \frac{\partial \tau_{yz}}{\partial y} + \frac{\partial \tau_{zz}}{\partial z} + F_z
\]  
(4)

where \( \rho \) is the pressure on the fluid cell, Pa; \( F \) is the force on the micro body, N; \( \partial t \) is the viscous stress on the micro-element caused by the viscosity of the molecule, N/m².

2.1.3. Energy conservation formula.

\[
\frac{\partial \langle \rho T \rangle}{\partial t} + \text{div}(\rho u T) = \text{div} \left( \frac{k}{c_p} \text{grad} T \right) + S_T
\]  
(5)

\[
\frac{\partial \langle \rho c_p \rangle}{\partial t} + \frac{\partial \langle \rho c_p u \rangle}{\partial x} + \frac{\partial \langle \rho c_p v \rangle}{\partial y} + \frac{\partial \langle \rho c_p w \rangle}{\partial z} = \frac{\partial}{\partial x} \left( \frac{k}{c_p} \frac{\partial T}{\partial x} \right) + \frac{\partial}{\partial y} \left( \frac{k}{c_p} \frac{\partial T}{\partial y} \right) + \frac{\partial}{\partial z} \left( \frac{k}{c_p} \frac{\partial T}{\partial z} \right) + S_T
\]  
(6)

where \( C_p \) is Specific heat capacity, J/kg*K; \( T \) is temperature, K; \( k/K \) is for the fluid heat transfer coefficient; \( S_T \) is for viscous dissipative term, J.

2.1.4. Turbulence model. Assume that the computer room model satisfies the Boussines hypothesis, The air flow in the data center computer room belongs to the air flow problem in a large space, so the standard model K-\( \varepsilon \), a turbulence calculation model for high Reynolds number, is selected.

\[
k = \frac{1}{2}(u^2 + v^2 + w^2)
\]  
(7)

\[
\varepsilon = \frac{\mu}{\rho} \left( \frac{\partial u^2}{\partial x} + \frac{\partial v^2}{\partial y} + \frac{\partial w^2}{\partial z} \right)
\]  
(8)

\[
\mu = C_{\mu} \rho k^2/\varepsilon
\]  
(9)

where \( \mu \) is flow viscosity; \( C_{\mu} \) is empirical constant.

2.2. The establishment of the physical model of the computer room

Build a 15m×13m×3.44m computer room, the raised floor is 0.64 m. There are 80 42U standard cabinets with a size of 600mm (width) × 900mm (depth) × 2050mm (height) in the computer room. Servers are placed in the cabinets. The heat dissipation of each server is the same, 4.8KW. The cooling load of the entire machine room is 400KW.

In order to specifically analyze the impact of different air supply methods on the energy consumption of the computer room, this paper selects three different air supply: under-floor air supply, under-floor air supply plus enclosed cold aisle, and inter-row air conditioning plus enclosed cold aisle for comparison. Establish models to simulate and analyze the temperature distribution of the computer room with three different air supply modes under the same air supply temperature and different air supply temperatures.

2.2.1. Under-floor air supply. The computer room adopts the air supply mode of raised floor and return air from the top of the air conditioner. Each cabinet has a floor grille before the air enters, and
the size of each grille is 600mm×600mm. The room is equipped with 4 precision air conditioners with a cooling capacity of 100KW, with dimensions of 2500mm (width) x 900mm (depth) x 1850mm (height). The size of the air return vent of the air conditioner is 2500mm×900mm. The air supply volume of each air conditioner is 8 m³/s. As shown in Figure 1, Figure 2.

2.2.2. Under-floor air supply and enclosed cold aisle. The air supply method in the computer room is the same as the under-floor air supply. The only difference is that the cold aisle is in a closed state, and the cold and hot air flows in the computer room cannot be mixed. As shown in Figure 3 and Figure 4.

2.2.3. Air conditioning between rows and enclosed cold aisles. The computer room uses 16 inter-row air conditioners with a cooling capacity of 25KW, with a power of 0.5KW, installed between the cabinets, and the air supply method of sending and returning from the front. The size of the air conditioning outlet and return air outlet is 500mmx1900mm and 550mmx2000mm. The cold aisle is closed. The air supply volume of each air conditioner is 6m³/s. As shown in Figure 5 and Figure 6.

3. Simulation result and analysis

3.1. The same supply air temperature
In order to better analyze the influence of different air supply modes on the temperature distribution of the computer room, first set the air supply temperature of the air conditioner to be the same at 18°C. Then, after simulation calculation, the temperature distributions at the horizontal heights of 0.8m,
1.8m, and 2.6m are taken respectively to obtain the temperature situation of the computer room under different air supply modes.

3.1.1. Under-floor air supply.

Figure 4. Temperature distribution diagram different level

Figure 5. Air conditioners return air flow chart

In the figure, the temperature of each level has obvious zoning, the lowest temperature is 18℃, and the highest temperature is 38.2℃. At the same time, the temperature in the computer room varies greatly between different heights, with temperature differences of more than 10℃ in some places. The air outlet temperature of each cabinet is generally high, reaching an average of over 30℃. The air outlet temperature of some cabinets closest to the air conditioner at a level of 1m above the air conditioner is above 38.2℃, showing obvious local hot spots. It can be seen from the figure that the area between the floor grille and the air conditioner is blue. The reason should be the return air of the air conditioner directly after coming out of the floor grille. For details, check the airflow organization in the computer room for further verification.

According to the airflow organization chart of the air conditioner return air flow, the cold air flow from the floor grille (indicated by the blue arrow) does not enter the cabinet, but part of it enters the air conditioner return air vent directly with the air circulation, and the other part is directly as shown in the figure. Flow to the top of the cabinet. Therefore, it can be explained why the temperature is lower near the air-conditioning opening and directly above the floor grille. The current airflow organization evaluation system uses the return air temperature index RTI to evaluate the airflow organization and management level near the cabinet. RTI uses the average inlet and outlet air temperature difference of the cabinet to quantitatively evaluate the thermal environment and cooling system efficiency of the computer room. To a certain extent, it reflects the mixing of cold and hot air in the computer room. Ideally, when RTI=1, it indicates that there is no serious mixing of cold and hot airflow in the equipment room; when RTI>1, it indicates that the cabinet is dominated by hot air recirculation (recirculation), otherwise, the cold air short circuit is the main reason. The farther the RTI deviates from 1, the worse the air distribution and the lower the thermal environment evaluation.

Calculated as follows:

$$\text{RTI} = \frac{T_r - T_s}{\Delta T_c} \times 100\%$$  \hspace{1cm} (10)
where $T_r$ is the return air temperature of the air conditioner; $T_e$ is the Air conditioning temperature; $\Delta T_e$ is the temperature difference between the average inlet and outlet air temperature of the cabinet.

After calculation, $RTI=0.67<1$, which indicates that the mixing phenomenon of cold and hot airflow in the computer room is serious, the cabinet is mainly short-circuited by cold air, and the cold utilization efficiency of the computer room is low.

3.1.2. Under-floor air supply and enclosed cold aisle. In order to avoid the under-floor air supply process, part of the cold air flow does not enter the cabinet but directly flows into the air-conditioning return air outlet or other areas of the equipment room, resulting in insufficient cooling capacity for the servers in the cabinet, which seriously affects the safe operation and life of the equipment. Therefore, a closed cold aisle is added on the basis of the above, and other setting parameters remain unchanged, and the simulation calculation is performed again. The simulation result is shown in Figure 7.

![Temperature distribution diagram different level](image)

Figure 6. Temperature distribution diagram different level

![Air conditioners return air flow chart](image)

Figure 7. Air conditioners return air flow chart

It can be seen from the figure that the temperature distribution at each level is relatively uniform, and there is no obvious temperature zone phenomenon. The temperature in the computer room is low, and the temperature difference between all levels is small. The average air outlet temperature of each cabinet is relatively low, about 27°C on average, and there is no local hot spot phenomenon. According to the figure, the cold airflow of the air conditioner is completely enclosed in the cold aisle, and the airflow organization in the computer room is better. The airflow from the cabinet smoothly enters the return air outlet of the air conditioner, and there is no whirling phenomenon in the corner of the computer room.

3.1.3. Under-floor air supply and enclosed cold aisle. Choose the air supply mode of air conditioner between rows and closed cold aisle, adopt the air supply mode of forwarding and returning. Establish a model for the air supply mode of the air conditioner between the computer rooms. The other set parameters remain unchanged, and the simulation calculation is performed. The simulation results are as shown in the figure below.
Figure 8. Temperature distribution diagram different level

It can be seen from the figure that the temperature distribution at each level is uniform, there is no obvious temperature zone phenomenon, and the temperature difference between each level is small, about 2°C. The air outlet temperature of each cabinet is relatively low, and the average temperature is below 30°C. The overall thermal environment of the computer room is good.

3.2. The different supply air temperature

In order to specifically analyse the increase in the supply air temperature of the system, the air supply method of inter-row air conditioning plus closed cold aisle and under-floor air supply plus closed cold aisle will be adopted under the condition of constant air supply. When the temperature is increased to 20°C, simulate and analyse the temperature distribution of different air supply methods, and compare with the under-floor air supply method.

Figure 9. Temperature distribution diagram at a level of 0.8m

Figure 10. Temperature distribution diagram at a level of 1.8m

Figure 11. Temperature distribution diagram at a level of 2.6m
According to the comparison of the temperature distribution of different air supply methods at the same level in the above figure, it can be seen that the temperature distribution of the air conditioner plus the closed cold channel between the rows is the most uniform, and the cooling effect is the best; the under-floor air supply and the closed cold channel are the second, and the temperature distribution is even. The cooling effect is better; the engine room where the air is supplied under the floor has obvious temperature zoning, and there are obvious local hot spots, and the cooling effect is the worst.

According to the computer room that adopts the air supply method of inter-column air conditioning plus closed cold aisle and under-floor air supply plus closed cold aisle when the air supply temperature of the air conditioner is increased to 20℃ and the under-floor air supply method where the air conditioning supply air temperature is 18℃ The temperature situation is compared. The air supply mode of inter-row air conditioners and closed cold aisles is still the best. The air supply mode of under-floor air and closed cold aisles is generally better, but the average air outlet temperature of some cabinets Higher, this may cause safety hazards.

4. Conclusion

This article uses 6sigmaDC software to establish three different air supply model computer room models, and then sets the relevant parameters, respectively simulates the different computer room models, so as to obtain the temperature field distribution and air flow distribution of different air supply modes. By comparing the simulation results, the following conclusions are obtained:

- When the air supply temperature is 18°C, the air distribution of the under-floor air supply method is disordered, the vertical temperature gradient in the equipment room is large, the air outlet temperature of the cabinet is high, and even local hot spots occur. Through analysis, the reasons for these problems are: One is the serious unevenness of the air supply of each floor grille under the floor, and the maximum air volume is more than 3 times the minimum air volume; the second is that the cold air flow in the computer room is not fully utilized, which makes the cabinet required insufficient cooling. Under the floor air supply plus enclosed cold aisle and inter-column air conditioning plus enclosed cold aisle, the two air supply methods enclose the cold energy in the cold aisle, so that the cold air flow is fully utilized, the heat dissipation effect of the cabinet is greatly improved, and the heat environment of the computer room is good.

- When the air supply temperature is 20°C, the overall thermal environment of the computer room with under-floor air supply plus enclosed cold aisle and inter-row air conditioning plus enclosed cold aisle air supply is better, which can meet the temperature requirements of the conference room and equipment, but using under-floor air supply and closed cold aisle air supply, the average air outlet temperature of some cabinets is relatively high, which may cause safety hazards.

- When the supply air temperature in the form of inter-row air conditioning plus enclosed cold aisle rises to 21℃, through simulation analysis, the computer room temperature reaches the limit for safe operation. Therefore, in the case of meeting the temperature requirements of the computer room, compared with the traditional under-floor air supply mode, the air-conditioning air supply temperature of the under-floor air supply and closed cold aisle air supply method can be increased by 2 ℃, and the inter-row air-conditioning and closed cooling can be increased. The air supply mode of the channel can be increased by 3 ℃, which can significantly reduce the energy consumption of the computer room.

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