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Air Distribution Optimization Research of Air Conditioning in Data Center Computer Room

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Abstract
To ensure the stable and reliable operation of the data center, the equipment in the data center computer room must be cooled. To study the influence of the temperature field and velocity field of the computer room on the cooling effect under different indoor air distributions in the computer room, based on the Fluent software, this paper conducts a numerical simulation study on the conventional air distribution plan and the closed cold aisle air distribution optimization plan of the research object. The temperature field and velocity field around the cabinet and the cooling effect in the cabinet are analyzed and researched. The results show that the use of closed cold aisles can significantly improve the problems such as the uneven temperature in the data center computer room, the poor cooling effect of the servers on the top of the cabinet, and cooling capacity loss caused by the mixing of supply and exhaust air. It has provided a basis and guidance for the subsequent design and transformation of airflow organization in the computer room.
Keywords: *Data center computer room, Air distribution, Closed cold aisle, Numerical simulation*

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I. INTRODUCTION

In the 1950s and 1960s, the information technology revolution broke out in human society. Computer technology developed rapidly. A large number of computers were put into use. The network was quickly integrated into all aspects of life and work. To adapt to the construction of the network, more and more data center computer rooms are established and put into use as information nodes. With a large number of data centers, air conditioners are widely used to control the temperature and humidity of data center computer rooms, so that server components can be kept in stable operating conditions. Due to the limited space in the computer room, the airflow organization of the computer room air conditioning system is unreasonable, and local heating becomes very serious. The research and analysis of the heating performance and airflow organization of the data center computer room has become a research focus in the field of computer room air conditioning at home and abroad [1-3].

In recent years, domestic and foreign experts and scholars have conducted in-depth research on the airflow organization in the data center computer room. At present, there are two main parts in the research on airflow organization of air conditioning in data center computer rooms. The first is to study the airflow characteristics in the cabinet and the computer room under the mode of floor air supply [4-6];

The second is to study the airflow characteristics in the computer room of the data center under the mode that the air conditioner in the computer room adopts the upward air supply and direct downward blowing [7-9]. With the development of computer technology, CFD technology has been increasingly used in the research of airflow organization of computer room air conditioning [10]. Researchers have done some corresponding studies, but there is little domestic and foreign-related literature on the airflow organization of closed cold aisles based on under-floor delivery.

In this paper, numerical simulation methods are used to conduct numerical simulation analysis and research on the conventional air distribution plan of the existing computer room of the data center and the air distribution optimization plan using closed cold aisles and provide suggestions and guidance for the air distribution design and transformation of the data center air conditioner.

II. FEATURES AND MATHEMATICAL MODEL OF AIR CONDITIONING IN DATA CENTER COMPUTER ROOM

2.1 Features of air conditioning system

The main equipment in the data center computer room is computer servers, data storage equipment, and communication equipment. These large numbers of dense hardware equipment will generate a large amount of concentrated heat load during long-term operation. The closed cold aisle is designed so that the air-conditioning cold air blown from under the raised floor enters the closed cold aisle and enters the front of the cabinet to take away the heat of the equipment. Due to the sealing effect of the fluid channel, the cold airflow can only pass through the server equipment inside the cabinet and conduct heat exchange with high-temperature components in the cabinet, After the cold air from the air conditioner absorbs heat, it enters the hot aisle from the rear of the cabinet. This can greatly improve the utilization efficiency of cold capacity. The basic principle of a closed cold aisle is shown in Figure 1.

To simplify the model, this article assumes that the air in the data center computer room is a radiant transparent medium and is incompressible. At the same time, it conforms to the Boussinesq density assumption. The airflow in the computer room is steady-state turbulence, ignoring the heat radiation on the inner wall of the computer room. In addition, because the data center computer room studied in this paper is located in the inner zone of the 7th floor, and the surrounding rooms are all air-conditioned rooms, the heat conduction caused by the temperature difference can be ignored, and the adiabatic boundary is assumed in the simulation. The gas flow satisfies the continuity equation, the motion equation, and the energy equation.

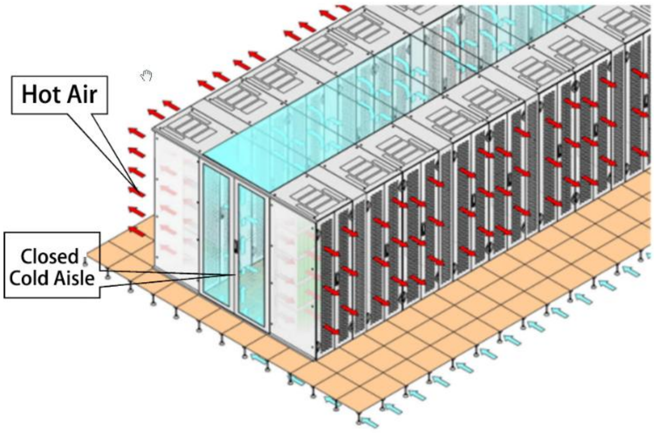


Fig.1: Schematic diagram of closed cold aisle

2.2 Mesh division and calculation conditions

In this paper, GAMBIT is used for grid generation of the numerical simulation model, and hexahedral grids are used to discretize the model space. Unstructured grids are used to generate grids for the entire circulation area, such as areas with large changes in velocity and temperature gradients, such as air outlets and return air outlets, for grid refinement processing. Moreover, according to the actual situation, the number of grid divisions is reduced when the calculation accuracy is satisfied, thereby improving the convergence speed and stability of the calculation.

This subject research uses the standard k-ε two-equation model with buoyancy correction [11] for calculation, and uses a pressure-based separation solver, introduces Boussinesq density assumption, and uses the default SIMPLE calculation method for pressure-velocity coupling. The discrete format of momentum and energy control equations, k and ε equations all adopt the first-order upwind style, that is, the unknown quantity on the interface always takes the value of the upstream node (node on the windward side).

The choice of the relaxation factor has an important influence on the iterative calculation process, and the appropriate choice of the relaxation factor can speed up the convergence. In this paper, the pressure sub-relaxation factor is set to 0.3, the temperature viscosity sub-relaxation factor is set to 1.0, and the mass force sub-relaxation factor is set to 0.1. The sub-relaxation factor of turbulent kinetic energy and turbulent dissipation rate is adjusted to be smaller according to experience based on the default value, set to 0.1-0.3. Other related parameters are shown in Table 1.

Table 1: Setting of relevant parameters for numerical solution

Turbulence Model	Variable	Temperature	Pressure	Momentum	*k*	*ε*
Standard k-ε two-equation model	Discrete Format	level one windward Format				
	Convergence Criterion	flow：1×10^{-3}；energy：1×10^{-6}				
	Under-relaxation Factor	1	0.2-0.3	0.1-0.5	0.3-0.5	0.3-0.5
	Solution Format	Temperature AMG	Pressure AMG	Momentum AMG	*k* AMG	*ε* AMG
	Cycle Type	Flex Type	V Type	Flex Type	Flex Type	Flex Type

III. MODEL ESTABLISHMENT

3.1 Conventional air organization model of the original computer room

The model is composed of a dedicated air-conditioning air outlet, a return air outlet, an orifice air outlet, a raised floor, a computer room cabinet, and two pillars in the computer room, as shown in Figure 2. For the processing of the orifice plate, in this order value simulation, the orifice plate is set as a porous jump [12], which is a two-dimensional planarization of the porous media model. Regardless of the thickness of the orifice, only the resistance coefficient and porosity of the orifice are set, and the heat transfer effect of the orifice is not considered.

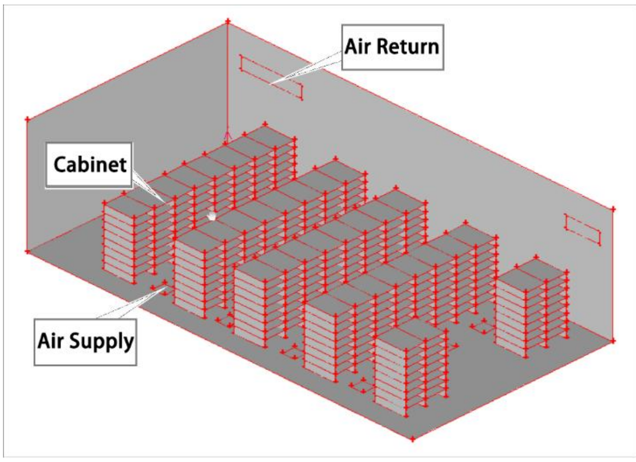
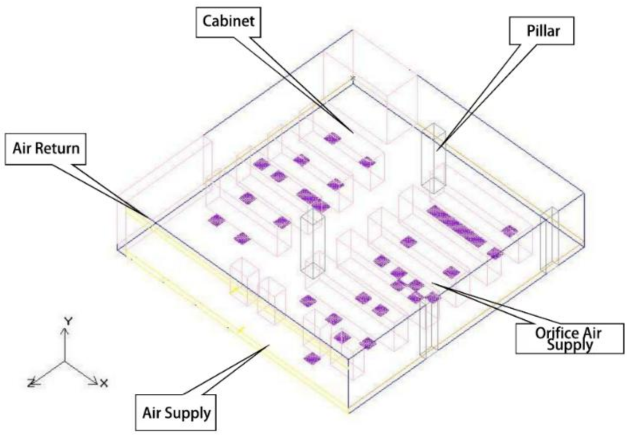
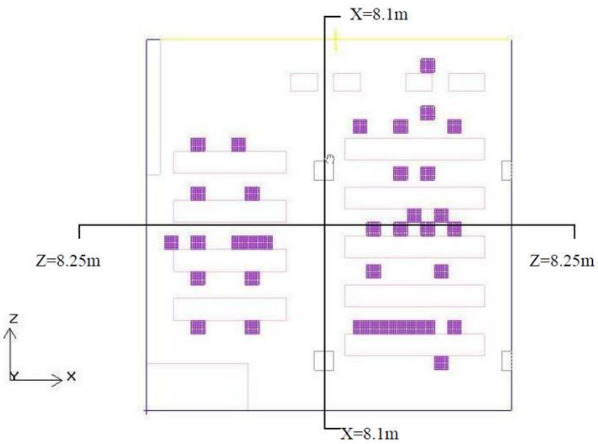


Fig.2: Conventional air distribution model of the original computer room

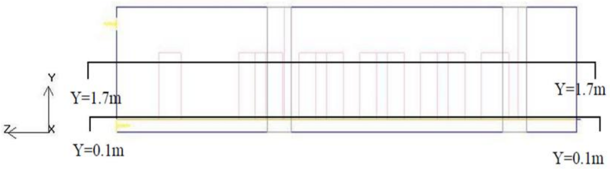
According to the actual computer room studied in this paper, the cabinet of the data center computer room is modeled, as shown in Figure 4(a)-(c), which is the physical model of the numerical simulation computer room.



(a) 3D model of computer room



(b) Bottom view of computer room model



(c) Front view of computer room model
Fig.3: Computer room numerical simulation physical mode

For the parameter settings of the numerical simulation model and the relevant parameters of the working conditions, see the Table 2 and 3, where "air supply area (15.6×0.4m2)" is the cross-sectional area of the static pressure box when the air outlet of the air conditioning unit enters the static pressure box.

Table 2: Parameter setting of conventional air organization model in computer room

Basic parameters of the computer room		Remark
Area /m^2	16.2×16.5	
High /m	3.8	On the ground 3.4m，underground 0.4m
Cabinet	13	11 at work
Cabinet heat /kW	164.38	18.36×8+5.5+6×2

Table 3: Parameter setting of sending and returning air from the conventional air organization model of the computer room

Air Supply Area /m^2	Air Supply Flow Rate/m^3/h	Supply air temperature /℃	Return air outlet area /m^2
15.6×0.4	13500	13.8	15.6×0.37
Air supply porosity of orifice plate	Number of orifice air outlets	Orifice plate air outlet size /m2	Air supply speed /m/s
0.2	36	0.6×0.6	3.2

3.2 Airflow organization optimization scheme model for closed cold aisle

According to the analysis of the results of previous studies, the existing problems of the air conditioning in the computer room are obtained, and the airflow organization optimization plan for the original computer room of the research object is proposed. The main contents include:

Based on the original air distribution form under the floor, the closed cold aisle air distribution form is adopted; the air leakage of the raised floor is blocked to ensure the airtightness of the raised floor; remove invalid openings; replace the insect-proof net of the return air grille, increase the effective area of the air return opening of the grille to reduce the return air resistance and increase the air supply of the unit; adjust the layout of the server equipment inside the cabinet so that it is installed and arranged from bottom to top from dense to sparse. The details are shown in Figure 4.

However, after the closed cold aisle is adopted, the cabinets in the data center are placed symmetrically, so the simulation model is one-half of the actual room of the research object.

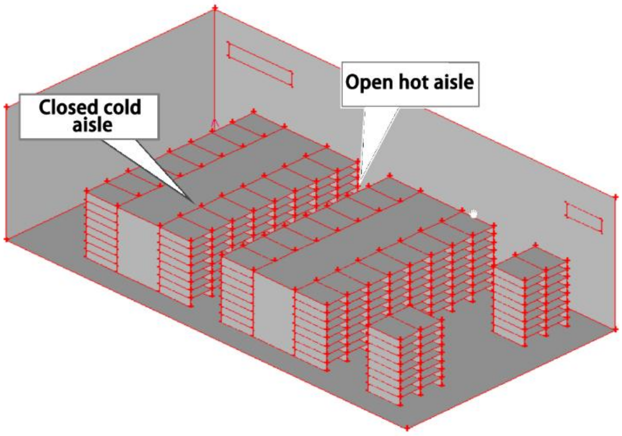


Fig.4: Airflow organization optimization scheme model for closed cold aisle

See Table 4 and Table 5 for parameter settings of numerical simulation conditions.

Table 4: Parameter setting of airflow organization optimization model for closed cold aisle

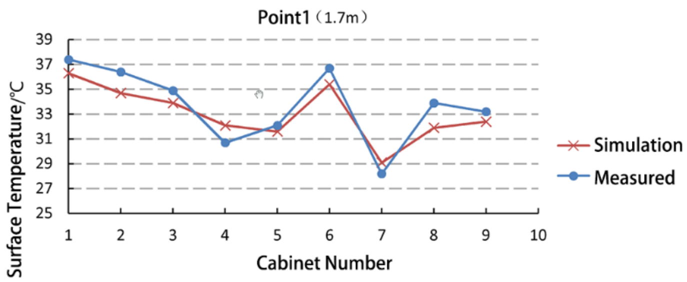
Basic parameters of the computer room		Remark
Area/m^2	16.2×10.5	
High/m	3.8	On the ground 3.4m，underground 0.4m
Cabinet	5+2	
Cabinet Heat/kW	85.44	18.36×4+6×2

Table 5: Setting of air supply and return air parameters for airflow organization model of closed cold aisle

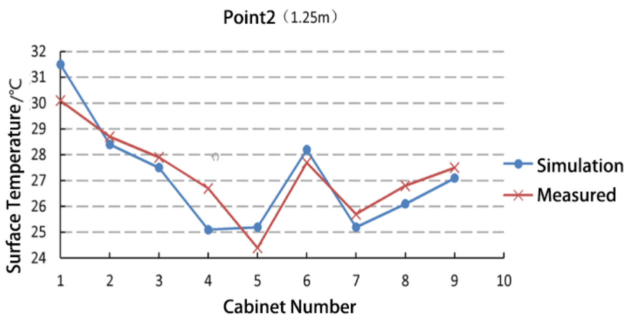
Air Supply Are/m^2	Air Supply Flow Rate /m^3/h	Supply air temperature /℃	Return air outlet area /m^2
15.6×0.4	6750	13.8	16.6×0.37
Air supply porosity of orifice plate	Number of orifice air outlets	Orifice plate air outlet size /m2	Air supply speed /m/s
0.2	18	0.6×0.6	3.2

IV. MODEL VERFICATION

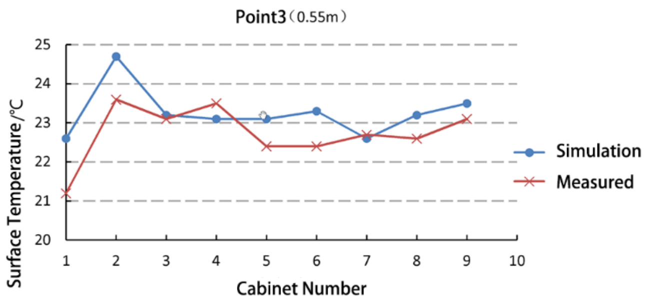
This paper compares the numerical simulation results with the experimental test results to verify the rationality of the numerical simulation. Compare the exhaust air temperature of the cabinet and the air supply volume of the orifice plate in the conventional air distribution plan of the original computer room. Select the measurement points on the exhaust side of the nine cabinets in the computer room at 1.7m, 1.25m, and 0.55m. The comparison between the simulated value of the exhaust air temperature of the cabinet and the experimental test result is shown in Figure 5.



(a) Comparison of the exhaust temperature of the cabinet at measuring point 1



(b) Comparison of the exhaust temperature of the cabinet at measuring point 2



(c) Comparison of the exhaust temperature of the cabinet at measuring point 3
Fig.5: Comparison of simulated and measured values of exhaust air temperature on the cabinet surface

Figure 5 is a comparison diagram of the cabinet exhaust temperature test value and the simulated value at each measuring point. The figure shows that the numerical simulation value is in good agreement with the experimental test result. The maximum difference between the simulated temperature and the actual measured value at each measuring point is 1.9 ℃, the maximum relative difference is 5.94%, and the average relative difference is 1.97%, indicating that the temperature simulation is reasonable, so the established numerical simulation model can be considered reliable.

In addition, the experimental results show that the average outlet temperature of each cabinet is 28°C, which is significantly different from the return air temperature of the entire computer room of 24.8°C.

V. SIMULATION RESULTS AND ANALYSIS

The main purpose of optimizing the air distribution of air conditioning in the data center computer room is to more effectively remove the heat generated by the equipment in the computer room during operation. Therefore, to study the influence of the closed cold aisle air distribution optimization program on the flow field in the computer room, this paper compares and analyzes the air distribution in the original computer room and the temperature field and velocity field after the optimization program is simulated and calculated.

5.1 Temperature field analysis

Figure 6 is (working condition 1 is the air distribution in the original computer room, working condition 2 is the optimized solution with closed cold aisle) to optimize the comparison curve of the exhaust air temperature of different heights of the cabinet before and after the optimization. The distance from the floor is 0.55m, the measuring point 2 is 1.25m from the floor, and the measuring point 1 is 1.7m from the floor.

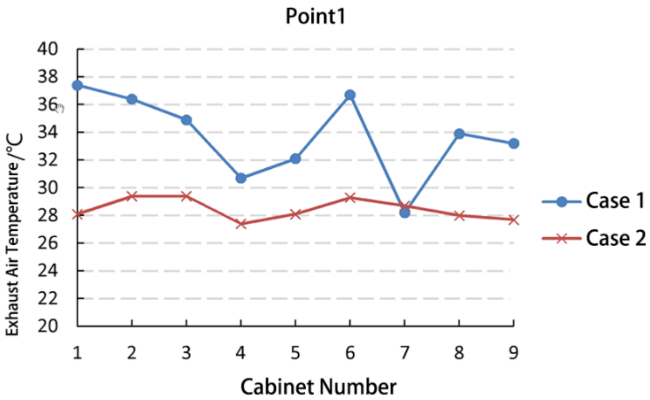
It is calculated that the average return air temperature after optimization is 28.9°C, which is an increase of 4.1°C compared to the airflow organization of the original computer room.

It can be seen from Figure 6(a) that the air distribution of the air conditioning in the computer room adopts the closed cold aisle to cool the upper part of the cabinet very obviously, and the exhaust air temperature is reduced by 5.3°C on average. This is because after the closed cold aisle is adopted, the attenuation of the air supply wind speed is slowed, and it plays a role in the orderly operation of gathering and organizing the cold air from the orifice into the equipment inside the cabinet, and the hot air exiting the hot aisle from the inside of the cabinet. The cold air does not participate in the mixing of the ambient air and the exhaust air of the cabinet, which greatly improves the effective air supply volume and increases the cooling efficiency.

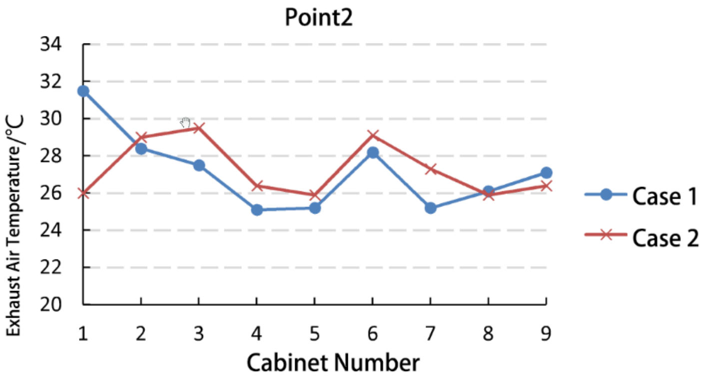
It can be seen from Figures 6(b) and (c) that after the closed cold aisle is used, the exhaust air temperature at the bottom of the cabinet is higher than before the airflow organization was optimized. After analysis, it is believed that the servers inside the cabinet were arranged in a dense to the sparse arrangement from bottom to top during the renovation, which is also part of the reason why the top exhaust temperature dropped so much after the renovation.

In addition, it can be seen from the data in Figure 6. After the airflow organization is optimized, the exhaust air temperature at each measurement point of all cabinets is basically within 29°C, which meets the exhaust air temperature requirements of the server equipment in the computer room and improves the reliability of equipment operation.

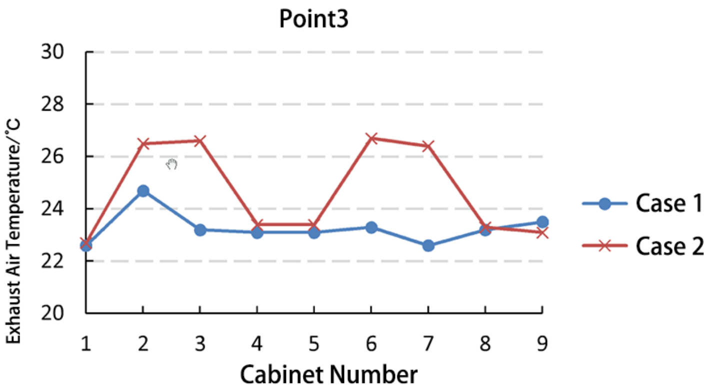
It can be proved that the use of closed cold aisle airflow organization can effectively solve the cooling problem of the server equipment in the data center, and can more effectively improve the utilization efficiency of the air conditioning cold in the data center computer room, and achieve more energy-saving effects.



(a)Comparison of the exhaust temperature at measuring point 1



(b)Comparison of the exhaust temperature at measuring point 2

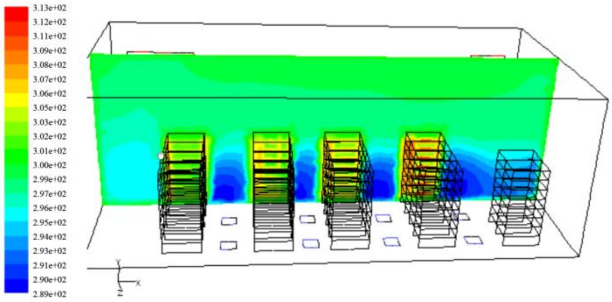


(c)Comparison of the exhaust temperature at measuring point 3

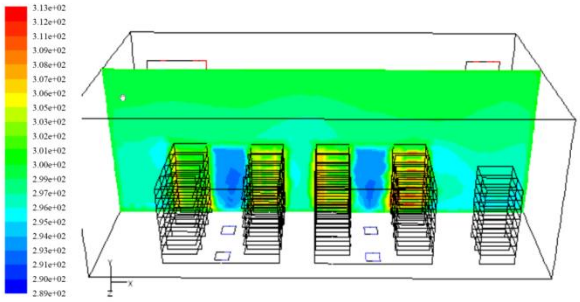
Fig.6: Comparison of the temperature values of the cabinets in the computer room before and after the optimization of the air distribution

Figure 7 shows the simulation results of the temperature field distribution before and after the optimization of the airflow organization of the research object. From the comparison of Figure 7(a)-(c), it can be found that after the cold air of the original equipment room airflow organization comes out from the orifice air outlet since there is no distinction between the hot and cold channels, the cooling capacity of the air supply stays around the air outlet and is difficult to enter the cabinet. Therefore, it is more difficult to improve the high-temperature environment inside the cabinet and near the surface, which easily causes the cold air from the orifice plate to mix with the high-temperature gas from the cabinet to offset the cold and heat. From Figure 7(a), it can be seen that the air from the supply air outlet tends to flow to the return air outlet, which will inevitably cause a loss of effective cooling capacity. From the comparison of the temperature field distribution in the cabinet at Y=1.7m in Figure 7(c) and (d), it can be seen that the internal heat dissipation of the original computer room cabinet is not smooth, forming a high-temperature zone.

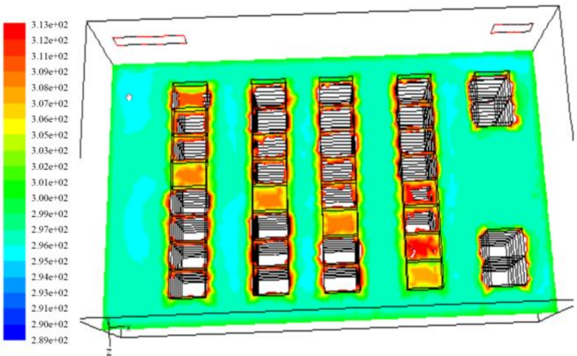
In this case, the overheating problem can usually only be solved by increasing the supply airflow rate and increasing the supply air cooling capacity. In this way, the energy utilization efficiency will inevitably be greatly reduced and the energy consumption will increase. In the airflow optimization solution, the internal temperature of the cabinet is lowered by an average of 4-5°C compared with the original computer room.



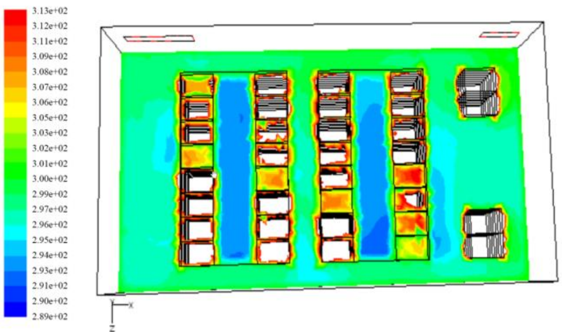
(a) The vertical plane temperature field of the original computer room



（b）Vertical plane temperature field of air distribution optimization scheme



（c）Y=1.7m horizontal temperature field of the original computer room



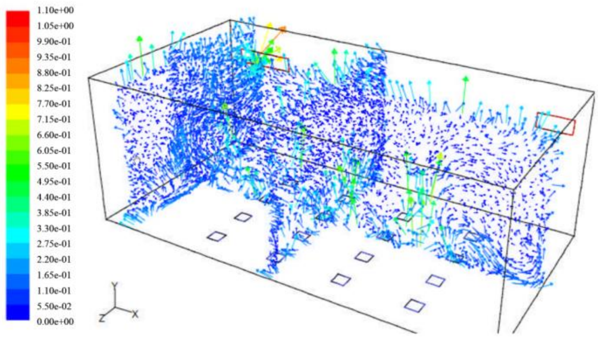
（d）Y=1.7m horizontal temperature field of air distribution optimization plan

Fig.7: Simulation results of temperature field distribution

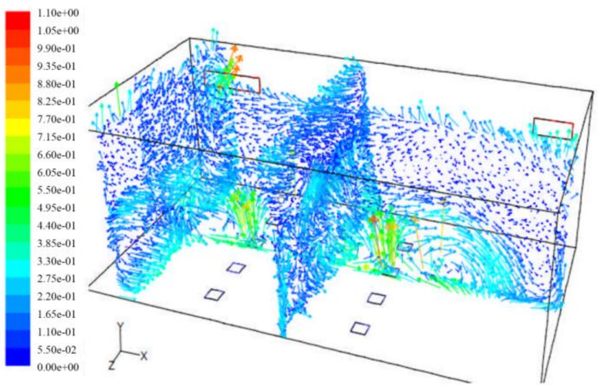
5.2 Velocity field analysis

Figure 8 shows the simulation results of the velocity field distribution before and after the optimization of the airflow organization of the research object. It can be seen from the speed vector diagram in Fig. 8 that the cooling capacity of the original floor of the original engine room stays within 1m, at a higher height, it is attenuated, and affected by the return air on one side, it flows directly to the return air outlet.

In the optimized scheme, under the action of the closed cold aisle, the cooling capacity of the floor can be increased to 2m, and the air pressure in the closed cold aisle is greater than that in the open hot aisle, which guides the cold airflow into the cabinet. The hot airflow in the cabinet is forced out of the cabinet, enters the hot aisle, and is brought to the air return vent along with the rise of the hot airflow and the effect of the return air. Through numerical simulation, it can be seen that the cooling effect of the closed cold aisle is significantly better than the original airflow organization, so it can provide a reference for the transformation of the existing computer room.



(a)Original computer room speed field



(b) Airflow organization optimization plan velocity field
Fig. 8: Simulation results of velocity field distribution

VI. CONCLUSION

This paper mainly conducts a numerical simulation of the cooling effect of the original conventional air distribution in the computer room of the data center through the closed cold aisle optimization scheme and compares the air distribution before and after the optimization of the air conditioning in the computer room through numerical simulation calculation. It provides a reliable basis for the subsequent design and transformation of airflow organization in the computer room. After analysis and research, it is concluded that the use of closed cold aisles can significantly improve the uneven cooling and heating in the data center computer room, the poor cooling effect of the servers on the upper part of the cabinet, and the cooling loss caused by the mixing of air supply and exhaust. The following conclusions can be drawn for the research object:

i. The use of closed cold aisle air organization reduces the mixing of cabinet exhaust air and orifice plate air supply and can increase the return air temperature of the original computer room from 24.8°C to 28.9°C while ensuring the cooling effect of the server. This greatly improves the utilization efficiency of cold capacity;

ii. After adopting the airflow organization form of the closed cold aisle, the internal temperature of the upper part of the cabinet (above 1.7m) decreased by 4-5°C on average relative to the original airflow organization, and the exhaust air temperature decreased by 5.3°C on average. In addition, the average exhaust temperature of each cabinet is basically within 29°C, which ensures the reliability of the operation of the data exchange components in the cabinet.

iii. The use of closed cold aisle airflow organization can avoid the mixing of hot and cold airflow in the upper part of the cabinet, insufficient airflow, and short-circuiting of airflow in the environment of the computer room. In addition, the ambient temperature of the data center computer room does not exceed 30°C, eliminating local hot spots caused by uneven air supply and internal circulation in the computer room.

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