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Research on optimization of airflow organization in badminton hall based on CFD simulation

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Abstract
In order to ensure a good indoor sports environment and air quality in badminton halls, this study conducted airflow organization simulations in a badminton hall within a high-rise office building in Shenyang, China, based on computational fluid dynamics (CFD). By comparing and analyzing two ventilation methods—upper supply and lower return, and lateral supply and lower return—the results showed that the latter was superior. In this method, the airflow distribution was more uniform, and the velocity attenuation was faster, making it more suitable for the airflow organization in badminton halls. Additionally, the lateral supply and lower return method could maintain a stable temperature range of 19-21°C, meeting the special environmental requirements of badminton halls and ensuring comfort during exercise. The results of this study provide a scientific basis and practical recommendations for the design and improvement of similar venues, further enhancing indoor environmental quality.
Keywords: *Computational Fluid Dynamics (CFD), badminton hall, airflow organization, ventilation method.*

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I. INTRODUCTION

The simulation of air flow organization in indoor environments has been a topic of interest in various studies. Researchers use numerical simulation methods to simulate the airflow inside the building to evaluate and optimize the built environment. Yik et al. [1] proposed a practical approach to evaluate the performance of natural ventilation in residential building design using computational fluid dynamics simulations and flow network simulation models. Elshafei et al. [2] conducted experimental and numerical studies to evaluate the effect of natural ventilation on thermal comfort in residential buildings, taking into account parameters such as wind speed, relative humidity, and air temperature. Pei-Chun [3] proposed a segmentation approach for natural ventilation design in tall office buildings, emphasizing the importance of evaluating airflow and thermal processes for year-round cooling potential. Wei et al. [4] conducted a study on the indoor thermal environment of an emporium with an atrium using CFD simulation to analyze the temperature and velocity fields under different air flow organization modes.

Airflow organization simulation plays a vital role in gymnasiums and is a key factor in ensuring that athletes can enjoy a comfortable and healthy indoor environment. Taking the badminton hall as an example, airflow organization simulation is not only of great significance for optimizing indoor air quality, but is also an integral part of improving players' sports performance that cannot be ignored. As discussed in a study by IOP science [5], the physics of badminton emphasize the role of airflow in the shuttle's drag coefficient during play. Incorporating airflow organization simulation into badminton halls can enhance player experience and overall air quality. Gyms can optimize airflow organization for better ventilation and comfort. Ventilation and air purification systems play a vital role in limiting aerosol particle concentrations in stadiums [6], emphasizing the need for adequate outdoor airflow rates. Different ventilation strategies and indoor air flow organizations have different control effects on indoor air quality in stadiums.

Therefore, this study conducted an airflow organization simulation for the design of a badminton hall in a high-rise office building in Shenyang, China, and simulated its air supply and exhaust forms to select a more suitable air supply and return method for the badminton hall to ensure indoor movement of people. While the movement of the ball is not affected, people's health and comfort are protected, providing reference value and significance for the design of similar badminton halls.

II. METHODS

2.1 The simulation model

2.1.1 Building Model

The model built is a badminton hall in an office building in Shenyang, China. It is mainly used for daily entertainment and training of employees and is not an international standard competition hall. Therefore, although the wind speed requirements are high, there is no need to meet the strict requirements of the International Badminton Association for the competition venue. The total height of the badminton hall is 10.25m, the net height after setting up the suspended ceiling is 9m, the east-west length is 33.9m, and the north-south width is 16.8m. The room is a tall space. Two commonly used airflow organization methods are now simulated, namely: diffuser air supply with upper and lower return, and nozzle air supply with lateral and lower return. The simulation results are analyzed and compared to obtain the optimal airflow organization design plan. Optimize the air conditioning system. The fluid in the badminton ball is regarded as an inviscid fluid, and the indoor air flow is a steady flow [7,8].

2.1.2 Mathematical model

This study used FLUENT simulation software to conduct an accurate numerical simulation of the air flow and heat transfer in the badminton hall. The standard k-ε two-equation model [9] is adopted. The standard k-ε two-equation model is currently the most widely used turbulence model.

2.2 Simulation process

Create a cuboid model

Use SolidWorks to create a cuboid model consistent with actual dimensions. The length is 33.9m, the width is 16.8m, and the height is 9m. After pre-selection and calculation, the size and number of air outlets at the top of the diffuser are obtained and arranged evenly. The return air outlet is set at a height of 1m from the ground on the side wall where the long side is located, and the size is calculated based on the actual situation. The air exhaust outlet is set at a height of 1m from the ground on the side wall where the short side is located, and the size is calculated based on the actual situation. The relevant model is shown in Figure 1 and 2. The choice of solver for this simulation is shown in Table 1

Table 1 Solver selection

Air supply methods	Upper Supply and Lower Return	Lateral Supply and Lower Return
pressure-velocity coupling equation solving algorithm	SIMPLE algorithm	SIMPLE algorithm
Interpolation method	First order upwind scheme	Second order upwind scheme
Gradient Interpolation Algorithm	Green-gauss node-based	Green-gauss node-based
Pressure Interpolation Algorithm	Standard	Standard
Pressure	0.3	0.3
Density	1	1
Body Forces	1	1
Momentum	0.35	0.7
Turbulent Kinetic Energy	0.7	0.8
Turbulent Dissipation Rate	0.8	0.8
Turbulent Viscosity	1	0.95
Energy	1	1

Meshing

Whether the meshing is reasonable or not has a huge impact on the convergence of the simulation results. The meshing scheme varies depending on the specific situation. The grid division of this plan adopts hexahedral grid, that is, structural grid division. During the simulation, the inlet and outlet of the airflow have a great influence on the accuracy of the indoor flow field simulation results. Therefore, the temperature and velocity of the supply and return air outlets are Where the gradient is large, the number of grids is enlarged to make the simulation results more accurate. The meshing result is shown in Figure 3 and 4.

Set boundary conditions

Set boundary conditions according to the design working conditions and calculated parameters. The boundary conditions of this scheme are shown in Table 2 and 3.

Table 2 Boundary conditions for the Upper Supply and Lower Return Airflow Organization

Border part	Boundary conditions	The parameters set	
Air supply outlet	Mass flow inlet	Mass flow rate	3.25kg/s
		Supply air temperature	18.3
Return air outlet	Outflow	None	None
Exhaust outlet	Outflow	Mass flow rate	1.5kg/s
Floor	Constant heat flow boundary distributes personnel heat dissipation to the ground	Heat flux	3.79W/m2
Suspended ceiling	Constant heat flow boundary distributes light heat dissipation to the ceiling	Heat flu	3.11W/m2

Table 3 Boundary conditions for the Lateral Supply and Lower Return Airflow Organization

Border part	Boundary conditions	The parameters set	
Air supply outlet	Mass flow inlet	Mass flow rate	3.25kg/s
		Supply air temperature	18.3
Return air outlet	Outflow	Outflow rate	0.532
Exhaust outlet	Outflow	Outflow rate	0.468
Floor	Constant heat flow boundary distributes personnel heat dissipation to the ground	Heat flux	3.79W/m2
Suspended ceiling	Constant heat flow boundary distributes light heat dissipation to the ceiling	Heat flux Heat flux	3.11W/m2

III. RESULT AND DISCUSSION

3.1 Model display

3.1.1 Final model

The results obtained are as discussed below.

Use Solidworks to build a cuboid model with a length of 33.9m, a width of 16.8m, and a height of 9 m.

Upper Supply and Lower Return: The air outlet size at the top of the diffuser is calculated to be 400mm x 300mm through air outlet pre-selection. In the direction along the length of the model, the distance between the outermost air outlet and the side wall is 3.36m, and the distance between the center points of each air outlet is 6.73m; in the direction along the width of the model, the distance between the outermost air outlet and the side wall is 2.8m, and each air outlet is 2.8m away from the side wall. The distance between the center points of the air outlets is 5.1m, and 15 air supply outlets are opened on the upper part of the cuboid according to the relevant dimensions. The return air vents are set at a height of 1m from the ground on the side wall where the long side is located. The size is: 600mm×500mm, 6. The air exhaust outlet is set at a height of 1m from the ground on the side wall where the short side is located, with a size of 800mm×600mm, see in Figure 1

Lateral Supply and Lower Return: The nozzle is set on the side wall along the length of the model, with a height of 8.5m from the ground. The distance between the outermost nozzle and the side wall is 1.54m. The distance between the center points of each air outlet is 3.08m. According to the relevant size requirements, it is installed on both side walls of the cuboid. Open 22 air supply outlets. The return air outlet is set on the same side wall as the air supply outlet, at a height of 1m from the ground. The size is: 400mm × 300mm. The number of air outlets is designed to be the same as the number of air supply outlets, 22. The exhaust outlet setting is the same as the upper and lower return methods, see in Figure 2.

3.1.2 Meshing result

Hexahedral grids, that is, structural grids, are used in the simulation. The inlets and outlets of the airflow have a great impact on the accuracy of the indoor flow field simulation results. Therefore, the number of grids is increased in places with large temperature and velocity gradients such as the supply and return air outlets, making the simulation results more accurate. The meshing results are shown in Figure 3. Since the convergence effect is not very good after the upper supply and lower return model meshing, the mesh is re-divided during the lateral supply and lower return model, as shown in Figure 4

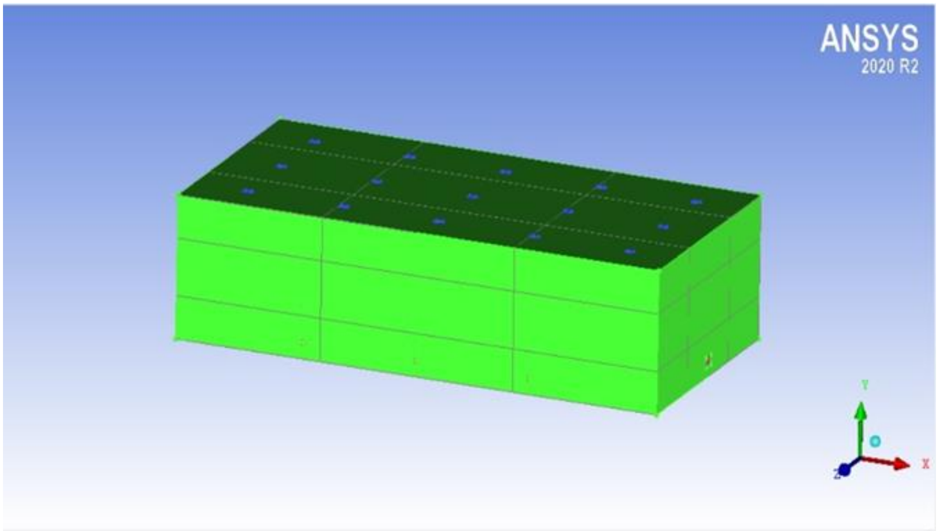


Figure 1: Badminton hall model of Upper Supply and Lower Return Airflow Organization

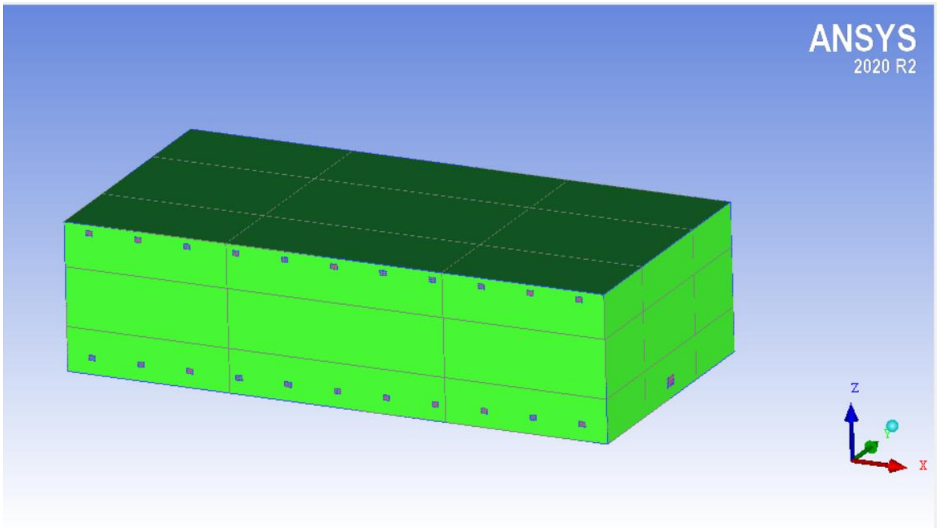


Figure 2: Badminton hall model of Lateral Supply and Lower Return Airflow Organization

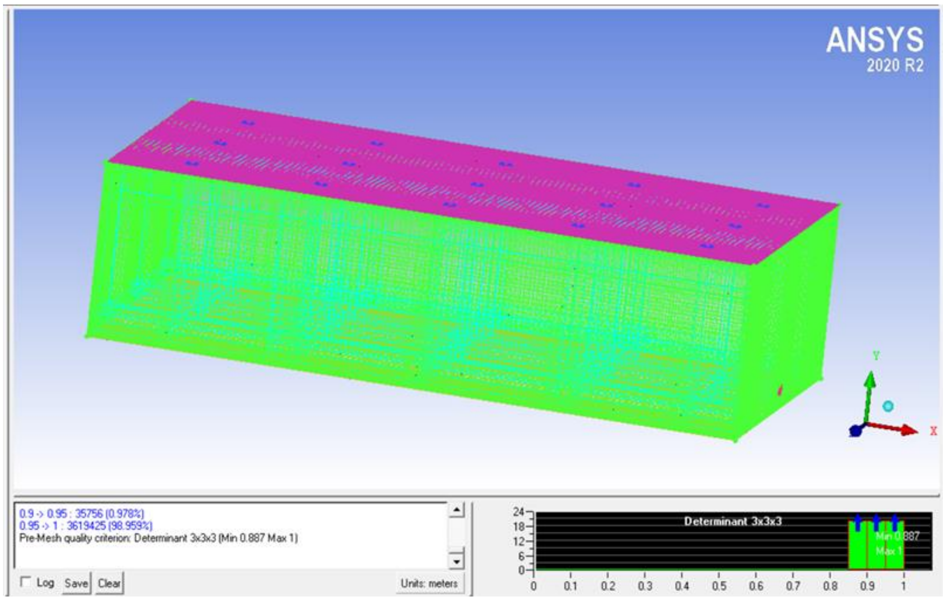


Figure 3: Meshing result of Upper Supply and Lower Return Airflow Organization

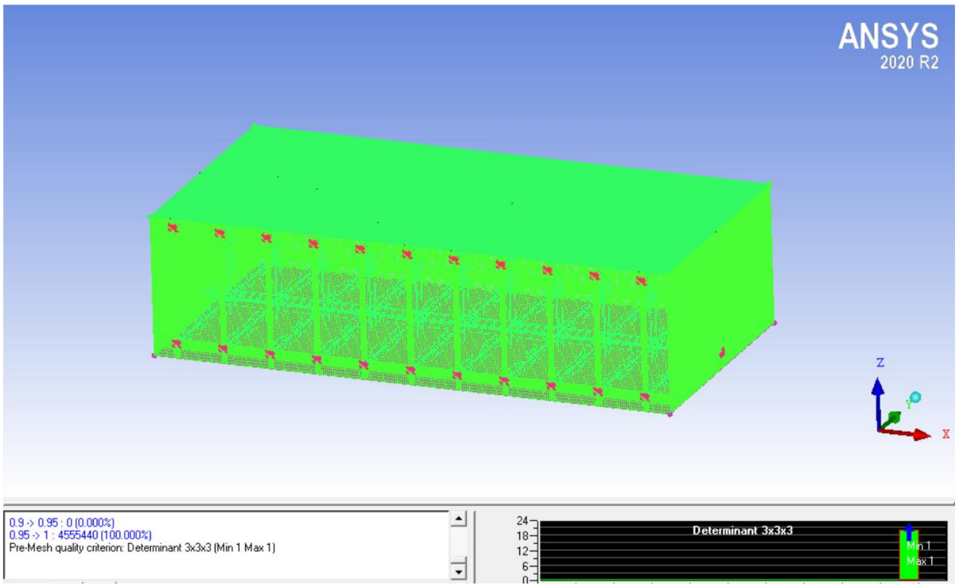


Figure 4: Meshing result of Lateral Supply and Lower Return Airflow Organization

3.1.3 Model convergence

The determination of the convergence principle reflects the accuracy of simulation calculations to a certain extent. In this study, the convergence criterion of the flow equation, continuity equation, turbulent kinetic energy equation and dissipation rate equation was set to 10^(-3), and the convergence criterion of the energy equation was set to 10^(-6) to simulate the residual curve of the final iteration. The graph is shown in Figure 5, and the results converge. However, due to the poor accuracy of the convergence results of the Upper Supply and Lower Return Airflow Organization, the mesh and solver settings were re-divided when designing the Lateral Supply and Lower Return Airflow Organization, and the flow equation, continuity equation, kinetic energy equation and dissipation rate equation were The convergence criterion of is 10^(-4), and the quasi-convergence criterion of the energy equation is 10^(-8). The residual curve of the final iteration of the simulation is shown in Figure 6. The results converge and the convergence is good.

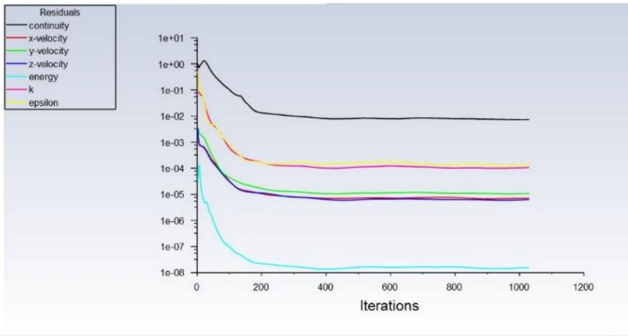


Figure 5: Badminton Hall Upper Supply and Lower Return Airflow Organization Convergence Results

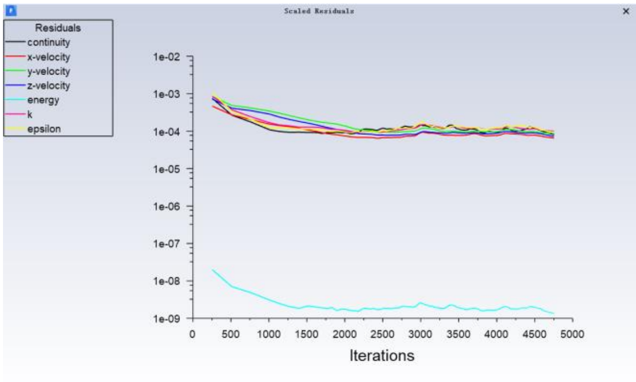


Figure 6: Badminton Hall Lateral Supply and Lower Return Airflow Organization Convergence Results

3.2 Comparative analysis of two Airflow Organizations

3.2.1 Velocity cloud chart at the air supply plane

The velocity cloud chart of the plane 9m above the ground, that is, the air supply plane of the diffuser, is shown in Figure 7. It can be seen that the wind speed at the air outlet complies with the set outlet speed, and the wind speed in the remaining parts is less than 0.2m/s, which meets the requirements of the badminton activity area.

The airflow distribution in the lateral supply and lower return airflow is basically symmetrical at a height of 8.5m above the ground (the plane where the center point of the nozzle is located).The jet axis wind speed is 0.33m/s, which is consistent with the jet axis velocity 0.33m/s calculated theoretically. Therefore, it can be judged that the simulation results are basically correct.

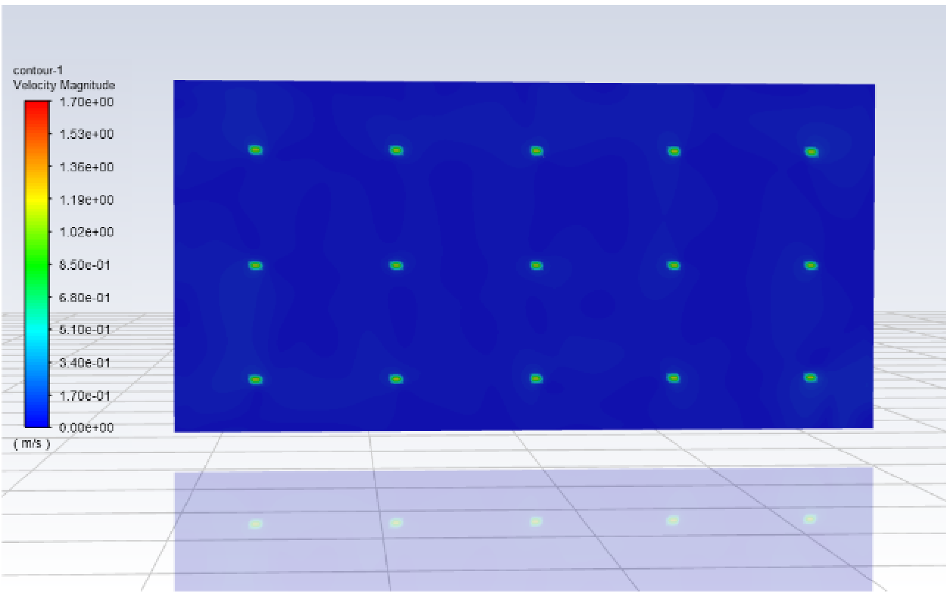


Figure : Velocity cloud chart at 9m above the ground of Upper Supply and Lower Return

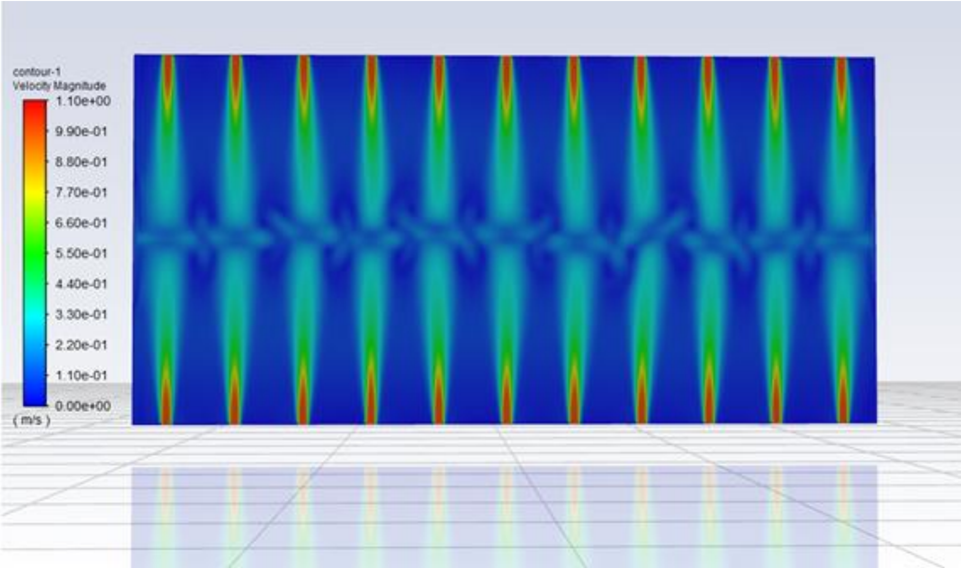
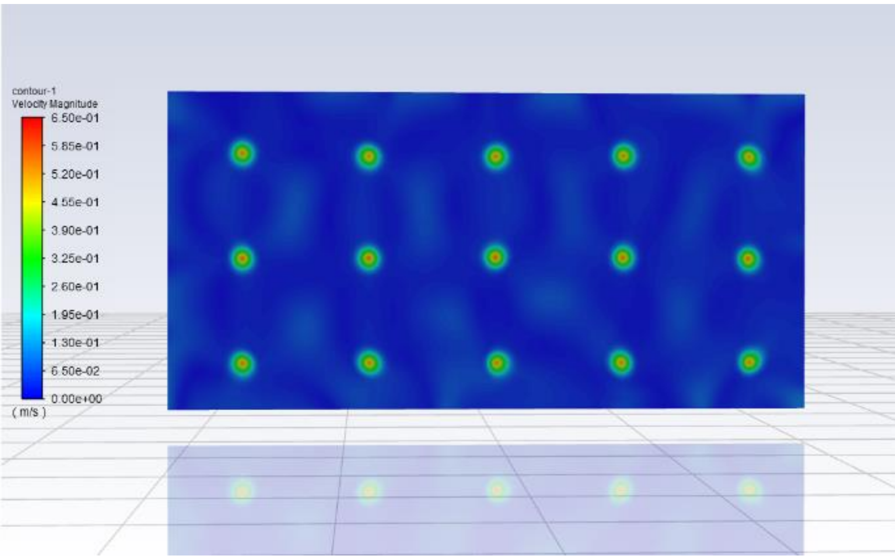


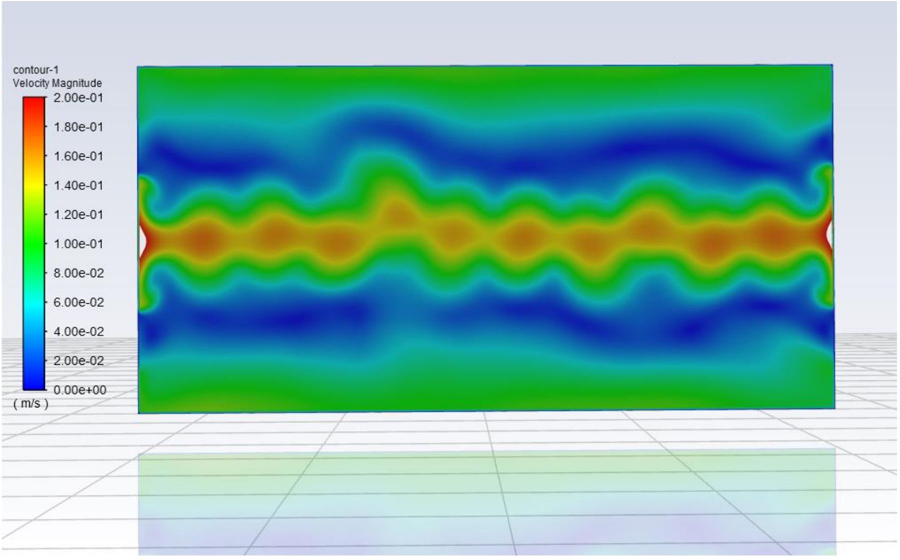
Figure 8: Velocity cloud chart at 8.5m above the ground of Lateral Supply and Lower Return

For badminton's high and long shots, the height will generally reach 5~6m. Therefore, a height plane of 6m from the ground is used to analyze whether the speed distribution meets the design requirements. The upper supply and lower return airflow organization is shown in Figure 9a), and the lateral supply and lower return airflow organization is shown in Figure 9b).

It can be seen from the velocity cloud chart that in the upper supply and lower return airflow organization, there is a circular area below the air outlet at a height of 6m with a wind speed greater than 0.2m/s, while in the lateral supply and lower return airflow organization, the airflow speed is basically less than 0.2m/s, which meets the requirements of the badminton activity area. Wind speed. Although there are places where the speed is close to 0.2m/s, since this venue is an entertainment and training venue for employees, the wind speed requirements do not have to meet the strict requirements of the International Badminton Association for competition venues, so the airflow organization plan for the lateral supply and lower return is feasible.



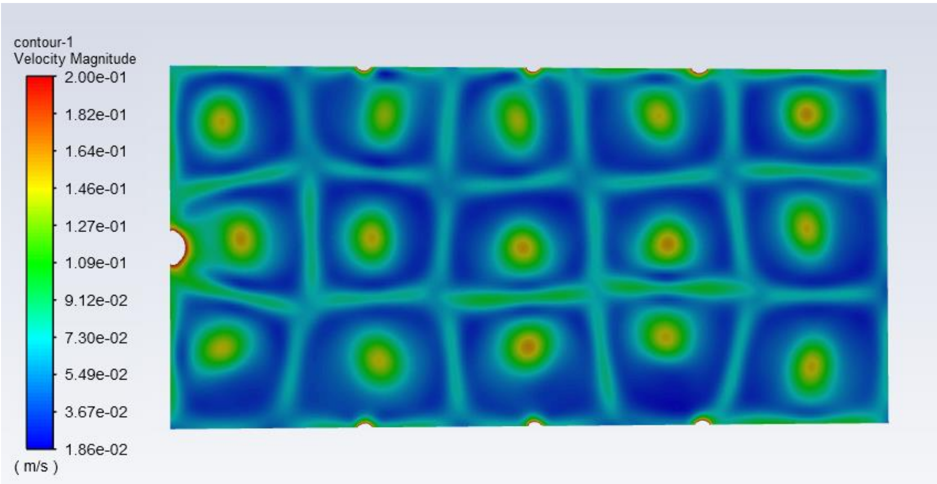
a) Upper Supply and Lower Return



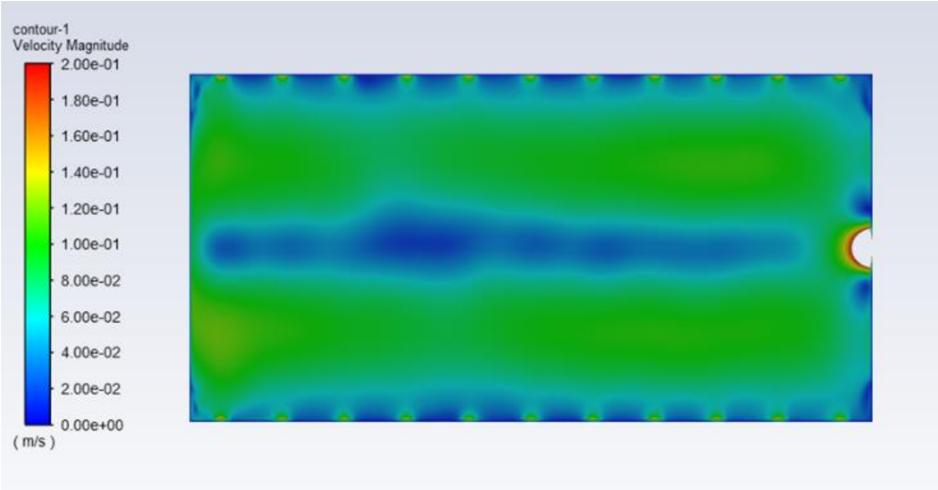
b) Lateral Supply and Lower Return
Figure 9: Velocity cloud chart at 9m above the ground

Because there is a table tennis table on the west side of the badminton hall room. After checking the design standards of the table tennis table, the height of the table top from the ground is 0.76m, so the velocity cloud diagram is observed at a height of 0.76m from the ground, as shown in Figure 10a) and b).

It can be seen from the analysis of the figure that the speed of the upper supply and lower return airflow organization on the plane of 0.76m above the ground is close to 2.5m/s, in the lower area where some air vents are facing. In the velocity cloud diagram of the Figure 10 b), the airflow velocity distribution is all less than 0.2m/s, so the airflow organization of the side-feed lower return can meet the requirements for playing table tennis. In the speed cloud diagram of the side-feed lower return, the airflow velocity distribution is all less than 0.2m/s, so the airflow organization of the lateral supply and lower return can meet the requirements for playing table tennis.

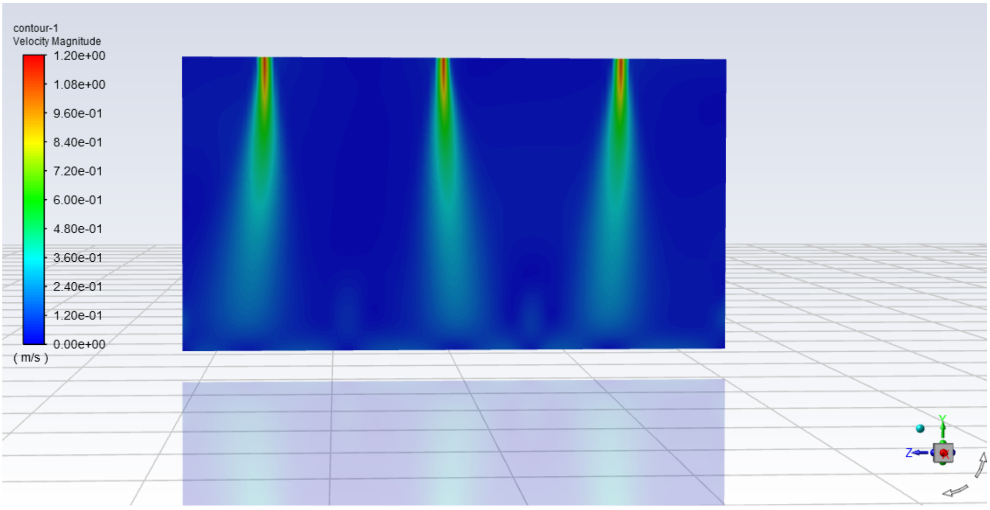


a) Upper Supply and Lower Return

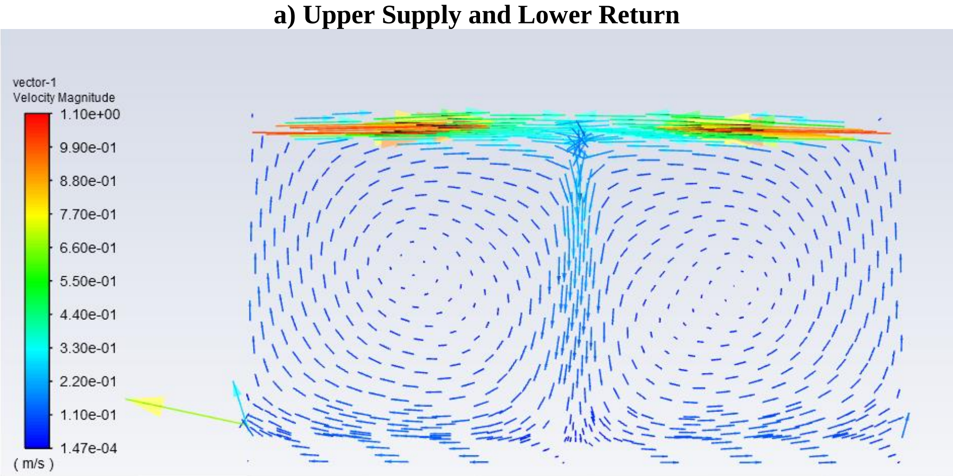


b) Lateral Supply and Lower Return
Figure 9: Velocity cloud chart at 0.76m above the ground

The longitudinal plane velocity cloud chart along the short side is shown in Figure 11a) and b)



a) Upper Supply and Lower Return

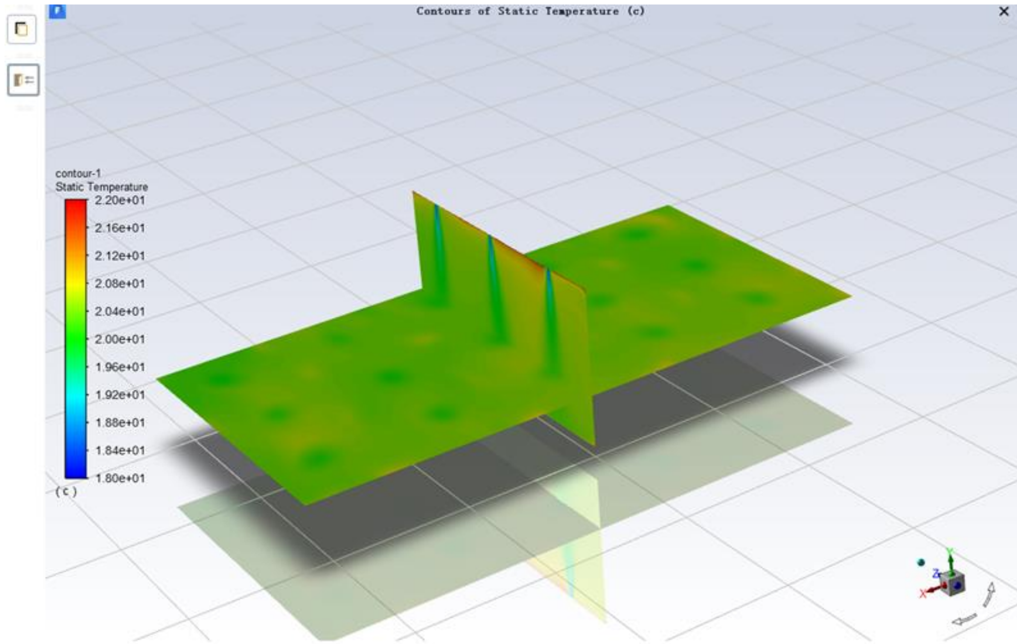


b) Lateral Supply and Lower Return
Figure 11: Longitudinal section velocity distribution vector diagram

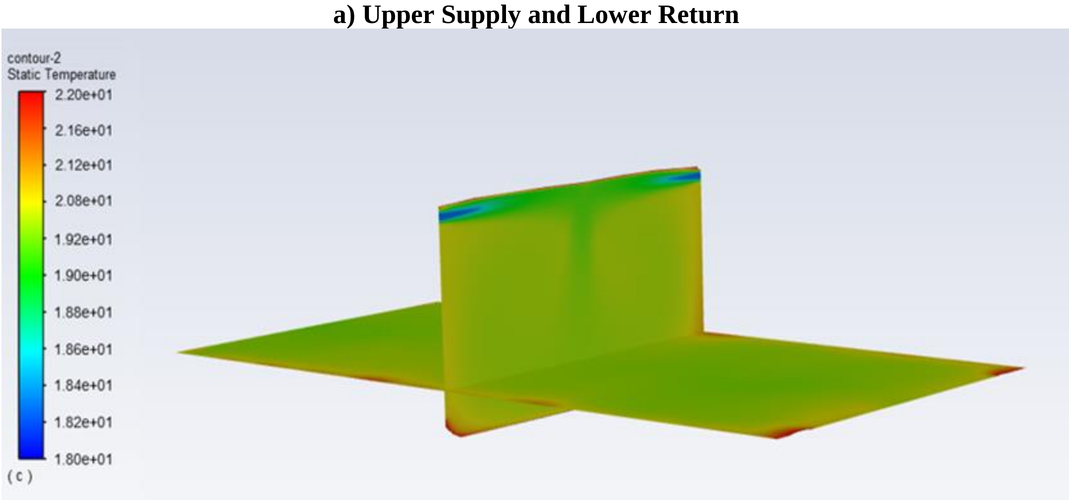
Since the diffuser sends jets up and down, the wind speed at the air outlet and the corresponding lower area is relatively large and attenuates slowly, so it cannot meet the design requirements on the required activity area plane. However, the analysis of the velocity vector diagram of the lateral supply and lower return shows that the active area is in the airflow swirling area, and the trend is consistent with the theory, and the velocity vector also meets the requirements.

To sum up, it can be seen from the four plane velocity distribution nephograms of the upper supply and lower return airflow organization that the three height planes above the ground and the longitudinal plane velocity along the short side do not meet the wind speed of the design work area ≤ 0.2m/s. The results show that the air outlet speed is large and the number of air outlets is too small, which does not meet the requirements. It is necessary to increase the number and size of the air outlets to reduce the air outlet speed. The disadvantage of this solution is that the airflow distribution in the air outlet and its corresponding lower part has a greater impact on the indoor airflow state, and has a negative impact on badminton and table tennis related activities.

The speed of the diffuser's upper supply and lower return mode attenuates in the longitudinal direction and the attenuation speed is slow. According to the above analysis, the number of air outlets and the outlet wind speed are both unreasonable. Therefore, in the airflow organization of the lateral air supply and lower airflow distribution are more uniform after increasing the number and position of the air supply outlet , and increasing the number and changing the position of the return air outlet. The speed is laterally attenuated and the speed is faster, which is more suitable for the airflow organization of the badminton hall.



a) Upper Supply and Lower Return



b) Lateral Supply and Lower Return

Figure 12 Work area temperature distribution cloud chart

In order to analyze these two air supply methods more comprehensively, we selected a vertical plane and a horizontal plane 2m above the ground as the temperature cross section to view the temperature distribution cloud chart. According to the results shown in Figure 12, it is believed that the temperature distribution is uniform, and the temperature in most areas of the room can be stably maintained within the range of 19~21°C. This temperature range not only meets the special requirements of badminton for the indoor environment [20], but also ensures people's comfort during exercising.

IV. CONCLUSION

The results obtained through CFD simulation show that under the airflow organization mode of the badminton hall's lateral supply and lower return, the airflow velocity distribution in the badminton hall is also more reasonable, and the setting of the air supply outlets makes the air flow velocity moderate. It can not only meet people's demand for air circulation during exercise, but also avoid the discomfort caused by excessive air flow. At the same time, the setting of return air outlet also effectively reduces the occurrence of unfavorable airflow phenomena such as vortices and dead corners in the hall. In addition, the simulation results also show that under the airflow organization mode of lateral supply and lower return, the temperature of the working area can be stably maintained in the range of 19-21°C. This temperature range not only meets the special requirements of badminton for the indoor environment [20], but also ensures people's comfort during training. This simulation result has important reference value for the design and optimization of badminton halls.

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