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Research on the cooling characteristics in building interior zones using displacement ventilation system

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Abstract

The outdoor low temperature fresh air can be used as a free cold source to eliminate waste heat for the building interior zones during the transition season and winter. This paper takes a project in Hunan as an example, and the project building interior zones is 25m×7m×3.9m(L×W×H). Using Fluent software to simulate the temperature field and velocity field both the interior and exterior zones of the engineering offices. The simulation results show that using the displacement ventilation system to take the outdoor air into inner rooms not only cooling but also improving the air quality and adding comfort. According to the simulation results and outdoor air dry bulb temperature and enthalpy values, the $h-d$ diagram is divided into three air conditioning conditions (summer, winter, transition season), and three different operation adjustment methods have been proposed corresponding to each air conditioning condition, which will reduce the energy consumption of air conditioning system.

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Keywords: Displacement ventilation system; building interior zone; adjustment scheme.

1. Introduction

With the improvement of living standards, people are increasingly demanding on the indoor environment, a good indoor environment is more conducive to people's physical and mental health. Indoor air environment includes indoor thermal environment and indoor air quality, ventilation is one of the reasonable measures to guarantee a good

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indoor thermal environment and air quality[1], also is an inevitable requirement of modern air conditioning technology. Displacement ventilation can not only provide a good airflow organization, create a comfortable thermal and humid environment, but also economic and energy saving[2].

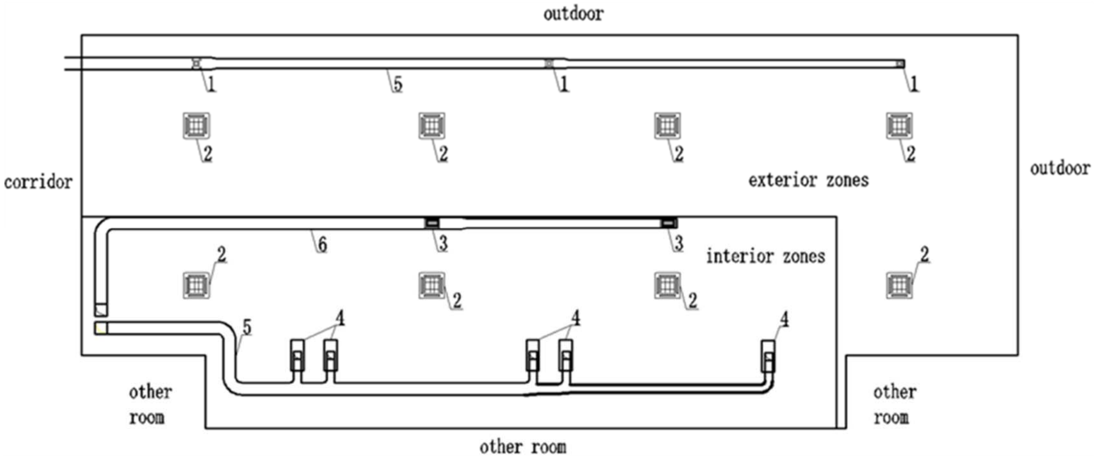
The area of its distance is away from the building exterior wall of 3~5 meters can be confirmed as the building interior zone[3], this zone temperature is little affected by the outdoor temperature, mainly affected by the human body, equipment, lighting and so on, even in winter, the interior zone temperature will remain high without the air conditioner work, which causes the indoor environment is not comfortable, so it is very necessary to eliminate the waste heat in the building interior zones in winter. Using the displacement ventilation system to send the outdoor low temperature air into the interior zones not only can improve the room air quality, increase the human body comfort, but also can reduce the energy consumption of air conditioning system, so deeply studying well about the indoor flow field parameters and characteristics in the interior zones cooling using the displacement ventilation system will be helpful to design and popularize better this system.

Based on this, this paper takes an actual engineering in Hunan province as an example and uses the Fluent software to simulate the temperature field and velocity field for a typical office interior and exterior zones by using computational fluid dynamics (CFD) analysis method. According to the simulation results and the outdoor air dry bulb temperature and enthalpy value, the diagram is divided into three air conditioning conditions (summer, winter, transition season), and three different operation adjustment methods have been proposed corresponding to each air conditioning condition, that will provide a theoretical basis for the creation of a good indoor environment.

2. Model establish

2.1. Physical model

The numerical simulation model of displacement ventilation system is based on the annual meteorological parameters in Changsha city, Hunan province. and the research object is a typical office with the size of 31m×13m ×3m (L×W×H). Considering that most of the office room windows are north and the heat load is large in winter, it is determined that this office interior zone is 6m away from the exterior envelope, so its size is 25m×7m× 3m(L×W×H). In the exterior zones of the office in winter and summer, multi-split air conditioning system is uses for heating and cooling, fresh air pipe is used for providing fresh air. In the interior zones, multi-spilt air conditioning system is used for cooling in summer, in the rest of time, replacement ventilation system is used for cooling and providing fresh air. In the interior zones, the design temperature is 26℃ in summer and 20℃ in winter. The air vents layout of the office is shown in Fig.1, the size of the replacement ventilation air supply outlet is 1000mm×400mm×500mm(L×W×H), the fresh air inlet size is 200mm×200mm, outlet size is 500mm× 320mm. The displacement ventilation system adopts double side air supply, and the air supply temperature is 23℃ in summer, 18℃ in winter, and 20℃ in transition seasons; the wind speed is 0.25m/s. The fresh air supply temperature is 26℃in summer and 20℃in winter, the wind speed is 3.68m/s. The air exhaust temperature is 27℃in summer, about 22℃ in winter, about 21.5℃ in transition seasons; the wind speed is 3.47m/s. Multi-split air conditioning indoor unit adopts four sides wind embedded, the inlet size is 500mm×50mm, air supply temperature is 18℃ in summer and 34℃ in winter, wind speed 2.45m/s; The outlet size is 500mm×500mm, air exhaust temperature is 27℃ in summer and 22℃ in winter, wind speed is 1m/s.



1.Fresh air inlet; 2. Multi-split air conditioning indoor unit; 3.Air exhaust outlet;4. Displacement ventilation system air supply inlet; 5.Fresh air pipe; 6. Exhaust pipe

Fig.1.Air vents layout of the office

2.2. Numerical model and network division

In order to simplify the model, reduce the mesh generation number, and save computing time, the radiators such as the equipment and personnel are simplified to 45 cylinders which size is 0.2m × 1.2m(R×H). Using tetrahedral structure method to divide the grid and generate 1.97 million grids. The convective heat and radiant heat components of the heat source must be analysed because the heat from heat source is not distributed in the activity area or the non-personnel activity area where the load is actually located. According to the literature[4], the heat production is divided into two parts: radiation and convection, the radiation model which adopts the DO model is added to the CFD calculation[5], this model considers the air as an incompressible ideal gas, and sets gravity acceleration of 9.8 m/s^2 along Z axis considering the influence factors of gravity. The finite volume method is used to solve the standard two equation model, and adopt the first - order upwind scheme to disperse equations[6]. The SIMPLE algorithm is used to deal with the coupling problem between pressure and velocity[7].

3. Simulation results and analysis

In order to study the indoor thermal comfort effected by displacement ventilation system in different seasons and different office heights, this paper analyses the temperature field and velocity field on the office height of 1.0m and 1.7m, respectively, and compares the distribution of temperature field and velocity field at different height of the room. and it also analyses the temperature distribution of the horizontal section at the height of 0.7m and 2.3m.

3.1. Indoor flow field in summer

Fig.2 and Fig.3 are the cross-section temperature distribution at Z=1.0m, Z=1.7m, Fig.4 and Fig.5 are section velocity distribution at Z=1.0m, Z=1.7, Fig.6 and Fig.7 are section temperature profile at Z=0.7m, Z=2.3.

From the different cross-section temperature distributions in Fig.2, Fig.3, Fig.6 and Fig.7, it can be seen that the temperature in the interior zone is about 26℃ and the temperature gradient is very small, which all has met the design standard. But, in some upper part of the work area, the air temperature will exceed 26℃, due to replacement ventilation supply air temperature lower than room temperature, it is easy to settle for cold air and rise for hot air in the room, so the thermal stratification phenomenon will exist, that is along with the increase of height, the air temperature increases gradually. From the velocity distribution at different heights in Fig.4 and Fig.5, it can be see that the displacement ventilation airflow distribution has been affected by other air outlets, but most of the office wind speed is lower than 0.2m/s, which has met the human requirements of indoor wind speed.

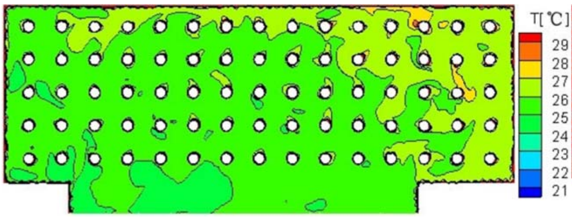


Fig.2.Cross-section temperature distribution at Z = 1m.

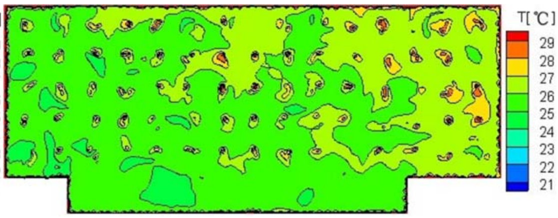


Fig.3.Cross-section temperature distribution at Z = 1.7 m.

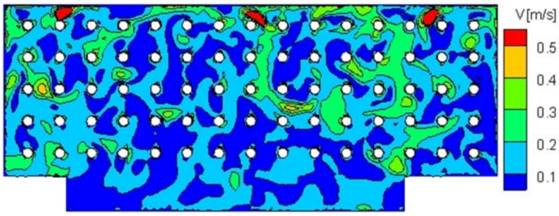


Fig.4.Cross-section velocity distribution at Z = 1m.

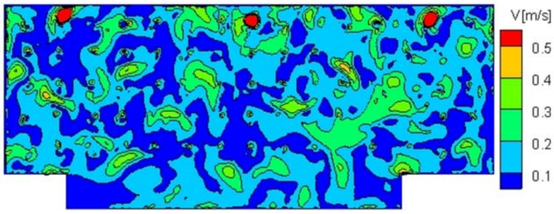


Fig.5.Cross-section velocity distribution at Z = 1.7m.

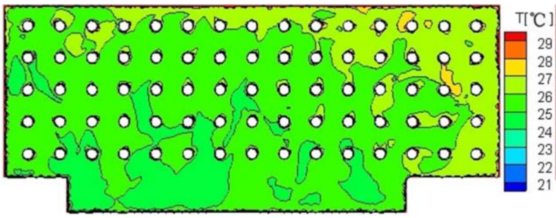


Fig.6.Cross-section temperature distribution at Z = 0.7m.

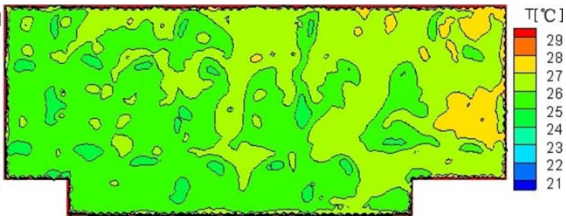


Fig.7.Cross-section temperature distribution at Z = 2.3m.

3.2. Indoor flow field in winter

Fig.8 to Fig.13 are the temperature field and velocity field distributions at the different height of office. From Fig.8, Fig.9, Fig.12 can be seen that the temperature is well distributed from 19℃to 21℃from Z=0.7m to Z=1.7m in the staff activity areas. Combined with Fig.13, it can be seen that the heat is gathered in the upper part of the room due to the action of the buoyant force, which results in a smaller temperature gradient in the working areas and guarantee the air quality of the work areas. Fig.10 and Fig.11 shows the velocity distribution at Z=1m and Z=1.7m, it can be seen that the cross-section velocity is well distributed and the wind speed is less than 0.1m/s without sense of blowing.

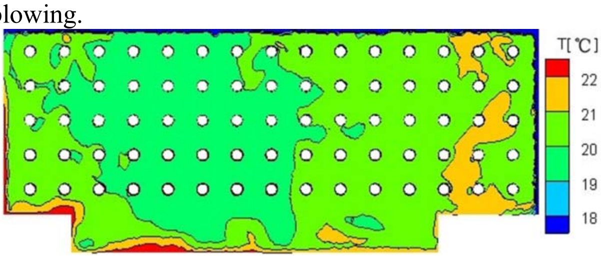


Fig.8.Cross-section temperature distribution at Z=1m.

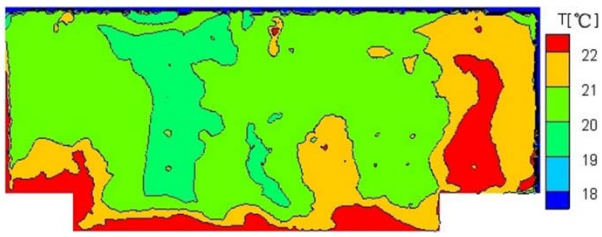


Fig.9.Cross-section temperature distribution at Z=1.7m.

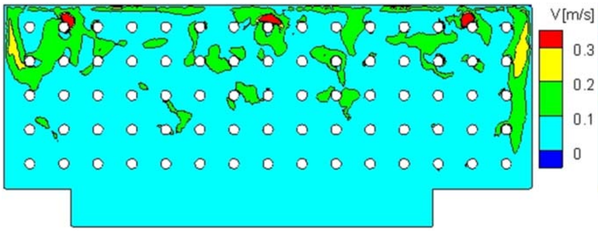


Fig.10.Cross-section velocity distribution at Z=1m.

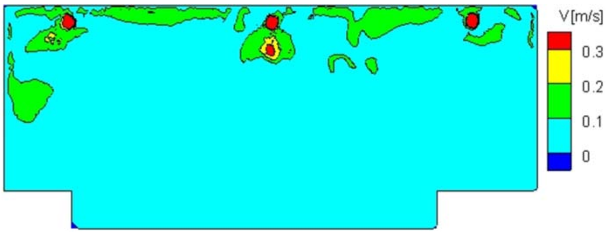


Fig.11.Cross-section velocity distribution at Z=1.7m.

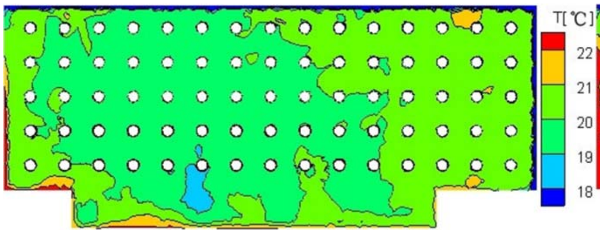


Fig.12.Cross-section temperature distribution at Z=0.7 m.

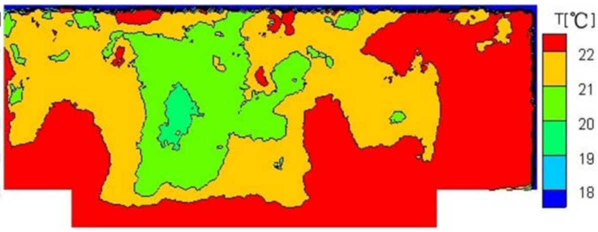


Fig.13.Cross-section temperature distribution at Z=2.3m.

3.3. Indoor flow field during the transition season

Fig.14 to Fig.19 are the temperature field and velocity field distribution in the different height of the office.

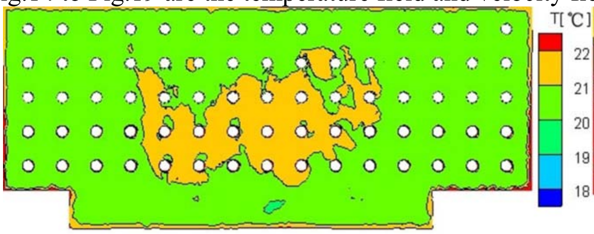


Fig.14.Cross-section temperature distribution at Z=1m.

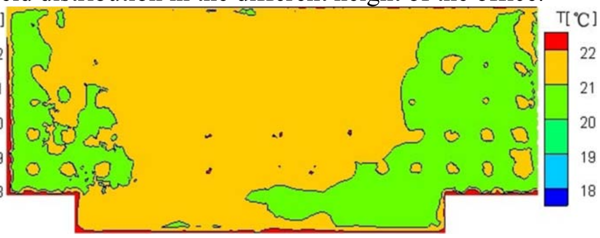


Fig.15.Cross section temperature distribution at Z=1.7m.

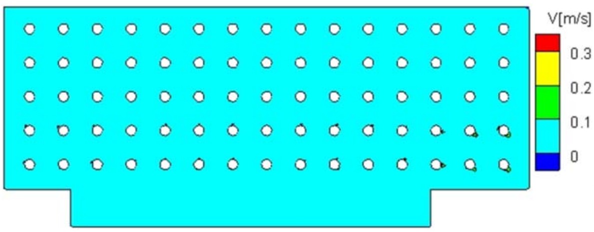


Fig.16.Cross-section velocity distribution at Z=1m.

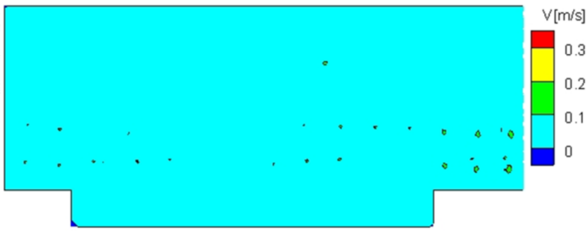


Fig.17.Cross-section velocity distribution at Z=1.7m.

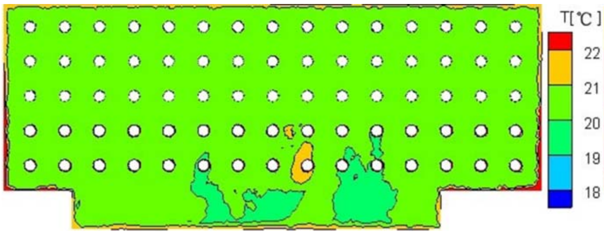


Fig.18.Cross-section temperature distribution at Z=0.7 m.

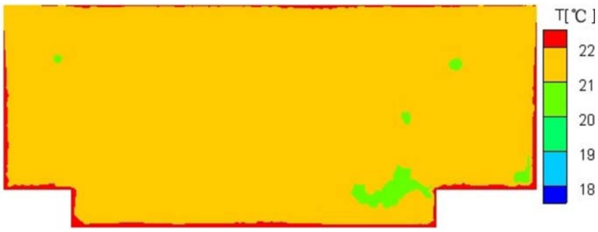


Fig.19.Cross-section temperature distribution at Z=2.3 m.

At this time, the airflow in the office is not affected by other equipment, because only replacement ventilation system provide fresh air with low wind speed and high air temperature state into the active region in the lower part of the office. The dirty air exhaust from the top of the room due to the combined effects of the air supply and up air flow from the indoor heat source. It can be seen from the temperature and velocity distribution figures at the different height that the indoor temperature is increasing with the room height is bigger, the temperature in the human activity area is about 21℃, and with good human body comfort. The displacement ventilation air supply velocity is set 0.25m/s, and it has decreased to 0.05 m/s when arriving at the work area. There is on sense of blowing with the indoor air almost no disturbance.

4. Annual operation control scheme of air condition system in interior

4.1. Operation control scheme in summer

When the outdoor air is greater than 22℃ and the air enthalpy value is greater than 43kJ/kg, it is identified as in summer, multi-split air conditioning indoor units are charged with indoor cold and wet load. In order to control the operation of the equipment such as start or stop and the pipe valve opening degree, the controllers must accepts the signals from the wet bulb temperature sensors which detect the temperature of the outdoor wet and dry bulb. Fig.20 shows the process of air handling enthalpy humidity in summer, the indoor air is handled from point N to point C by the multi-split air conditioning indoor unit, the outdoor fresh air is handled from point W to point L which is the same enthalpy with point N, the fresh air is not charged with indoor load. The fresh outdoor air is supplied with low flow into the work areas by displacement ventilation. Fresh air point L and indoor air point C is mixed to the point O[8], then handle the waste heat and humidity in the room. The dirty air above the working area is discharged to the outside through the exhaust system with the total heat exchanger to recover the heat.

4.2. Operation control scheme in winter

When the outdoor air is less than 18℃ and the air enthalpy value is less than 35kJ/kg, it is identified as in winter. Due to the mutual reduction of cold and hot load in the interior and exterior zones, the interior cold load in winter is less than that in summer. The outdoor fresh air with low temperature and enthalpy should be directly used for cooling to replace the artificial cold source. It is not necessary to consider the problem of fresh air humidification according to the characteristics of low temperature and high humidity in winter in Changsha city. Fig.21 shows the process of air handling enthalpy humidity in winter, the fresh air is filtered simply and preheated from point W to point O by the fresh air unit and then is sent into the room to absorb the indoor heat and moisture. In order to guarantee the comfort in working zones, it is not adopted that increasing the air supply temperature differences and reducing the air supply flux. It is a simple and effective way to use the low temperature outdoor air instead of artificial cold source with displacement ventilation system, which will not only maximize the advantages of fresh air in improving indoor air quality, but also save the operation cost and control flexibly.

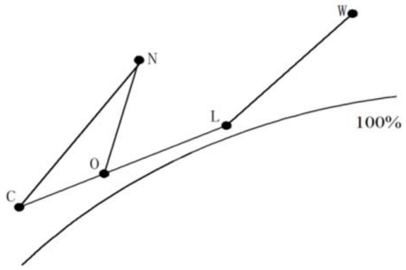


Fig.20 Theenthalpy humidity chart of air handle process in summer

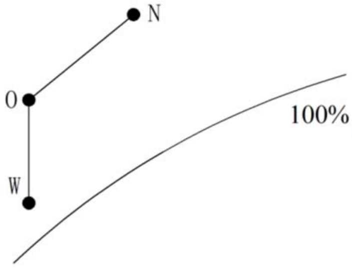


Fig.21 Theenthalpy humidity chart of air handle process in winter

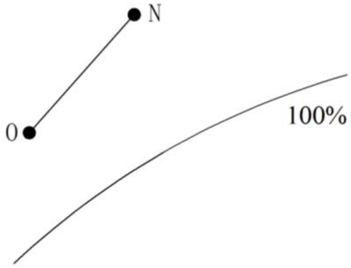


Fig.22 Theenthalpy humidity chart of air handle process in transition season

4.3. Operation control scheme in transition season

When the outdoor condition is not in aforementioned conditions, it is identified as in transition season. Fig.22 shows the process of air handling enthalpy humidity in transition season, the fresh air is filtered simply then sent into the room to absorb the indoor heat and moisture. The multi-spilt air conditioning system, fresh air units, and heat exchangers are stop running[9]. In order to meet the demand of human comfort and health conditions, the air supply flux of replacement ventilation system is adjusted and controlled by fan revolutions which are controlled by the fan inverter output frequency and it receives the signs by placing the temperature sensor in room.

Therefore, the displacement ventilation system is used in interior zones for cooling, not only achieving good air quality, reducing cooling load, extending free cooling time, but also saving air conditioning energy consumption and reducing operating costs.

5. Conclusion

Based on the numerical simulation of displacement ventilation system, the temperature and velocity fields in different height are compared, the conclusions are as followed:

In summer, adopting mixed ventilation equipment, displacement ventilation airflow organization is disturbed by other units, although the temperature field and velocity field distributions is somewhat cluttered, the temperature is maintained about 26℃ and the wind velocity is lower than 0.2m/s in working area, which will guarantee people's thermal comfort.

In winter, outdoor air is used to eliminate the cooling load in building interior zones, the temperature field and velocity field is well-distributed in work areas, the temperature is about 19℃～21℃, the average temperature gradient is 1.25℃/m and wind velocity is less than 0.5m/s.

In transition season, displacement ventilation airflow organization is not affected by other units, indoor air forms upward airflow under the action of buoyancy, the temperature in upper part is higher than that in lower part of room, the air quality is improved significantly because the hot turbid air which gathered in the upper part of the room is discharged out by displacement ventilation system.

Acknowledgement

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