Study on the thermal performance under the implement of multi-vent module-based adaptive ventilation

Weijia Zhang1, Weirong Zhang1*, Haotian Zhang1

1 Key Laboratory of Green Built Environment and Energy Efficient Technology, Beijing University of Technology, Beijing, China

Abstract. Indoor occupants' distribution scenarios are in a dynamic change randomly. Moreover, in many occasions with fixed seats, people in areas where cold air blows directly have a poor thermal experience. Therefore, to meet the differentiated environmental demands, novel ventilation strategies to satisfy the changing environmental requirements needs to be explored. In this study, a multi-vent module-based adaptive ventilation (MAV) system with a multi-vent dynamic ventilation module as a core is proposed to increase the adjustability of air distribution and better adapt to variable demands. MAV has three control characteristics of zoning division, completion of the inlets and outlets conversion, and the use of dynamic airflow adjustment. Simulations are conducted based on a typical multifunctional classroom with four common scenarios. The performance of MAV and MV under different scenarios is compared by considering airflow pattern, SVE4, PMV and DR. The results reveal: this ventilation module can effectively realize the zoning division control. MAV can create a more comfortable thermal environment when compared with MV. Various vents schemes realized by the function of the reversing device create different airflow patterns and thermal environments, which can be matched to diverse indoor scenarios. When the indoor scenario changes, the local uncomfortable state can be improved by switching the device to change the vents schemes. In order to deeply adjust thermal discomfort caused by the airflow pattern of downwards under the multi-vents air supply, it is reasonable to introduce dynamic airflow in MAV to improve the draught comfort. This ventilation strategy might be expected as a promising air terminal system that provide flexibility and adaptability for real applications.

* Corresponding author: zhangwr@bjut.edu.cn
1 Introduction

To further create a healthy, efficient, and comfortable indoor environment, variable dynamic ventilation is proposed to regulate and control the indoor environment from the perspective of ventilation construction. It is particularly important to choose a ventilation method that fully consider the changing indoor demands. Although many researchers have proposed many advanced ventilation methods, their characteristic is that a certain method is effective under a certain situation. And they still need to be predesigned and operated using a fixed flow pattern upon installation. Once the design of the air terminal system is determined, the ventilation system cannot be changed in subsequent application. In other words, indoor airflow is not adjustable. There is a gap in terms of a proper air terminal system that can provide flexibility and adaptability for real applications.

To fill this gap, this study proposes a novel air terminal system—multi-vent based adaptive ventilation (MAV) system that comprise multiple ventilation modules. The system can change the vents schemes according to demands by a reversing device. The basic idea of MAV system hinges on using multiple small vents to create different airflow patterns based on the ventilation demands. The emergence of MAV can be used as a suitable air terminal system for demand-oriented ventilation.

2 Methodology

2.1 System description

Considering the properties, the system is named as multi-vent module-based adaptive ventilation (MAV).

A schematic diagram of MAV is illustrated in Fig. 1. The module includes a switching device, four vents (two inlets and two outlets) and other ducts. The ventilation module is considered as the minimum unit of MAV. As a modular device, its application will be combined according to the scale of the building to become a complete system.

Each module has three switching schemes controlled by the switching device, which can realize the switching of the air duct through the rotation of the rotor. If this module is mounted independently, control in a small scope can be fulfilled. Systematic layouts can provide suitable solutions for environmental control in typical scenarios.

2.2 Thermal environment control

In the section, thermal environment control effects of MAV will be introduced. The effects consist of the following three levels: zoning division, switching vents schemes and generate dynamic airflow to improve local thermal comfort deeply. In theory, MAV will gradually improve the indoor environment from these operations: (i) divide the full space into many sub-zones spatially and control them independently; (ii) accomplish different vents schemes by switching multi-vents to adapt to the changing scenes; (iii) in terms of time, pulsating air supply can be used to further improve indoor thermal comfort.

2.3 Case design

In this study, a multifunctional classroom was established as a geometric model shown in Fig. 2. The overall dimensions of the model were 10.0 m (length) × 8.0 m (width) × 3.0 m (height). The layout of the classroom can be changed to respond flexibly to changing scenarios.

To discuss the effect of MAV on thermal environment, four ventilation modules were designed to study the effects of single and combined use. Therefore, there were sixteen vents in total. The size of small vents was 0.20 m × 0.20 m. They can be used as either inlets or outlets by using the rotor. As illustrated in Fig. 3, four common scenarios were considered here. Then, their suitable vents schemes were chosen based on certain principles, as shown in Fig. 4. Here, the principle is avoiding the draught sensation. The performances of thermal environment under the application of MV and MAV systems were explored. For MV system, four large vents were used to represent sixteen small vents, in the form of same-side supply air and return air.

Fig. 1. Schematic diagram of multi-mode dynamic ventilation module.

Fig. 2. Configurations of the model.

Fig. 3. Multi-vent ventilation module.

(a) Scenario a. General (b) Scenario b. Discussion
The boundary conditions were set as follows: the heat flux of the human body was set to 40 W/m², the computer released a heat load of 100 W/m². The supply air temperature was 22.5 °C and velocity was 1.2 m/s.

The simulation was carried out using the commercial CFD software ANSYS Fluent 2020. The turbulent flow was simulated using the standard k-ε model. A standard wall function was used to model turbulent flow in the near-wall region.

The following will compare the thermal performance of MAV and MV according to the designed cases, and intend to verify the three control advantages of MAV mentioned in 2.2.

3 Results and discussion

3.1 Zoning division

For the verification of the first feature, SVE4 [1] indicating the sphere of influence of the supply air was selected. Taking module 3 as an example, the results of SVE4 at the two air supply vents of the module are given in Fig. 5. The influence scope of fresh air from a supply air vent can be seen clearly. There is a very high value below the air supply inlet, indicating that the supply air has a great influence on the space below it, reaching more than 0.7. It has little influence on the air supply inlet in another ventilation module on the same section. For plane a, when the supply air reaches the breathing space, SVE4 decreases to 0.6, and SVE4 of the overall working zone is above 0.5. The higher the height, the lower the influence degree of the air supply in the zone. For plane b, the scope of air supply is less than that of plane a.

In contrast, in MV system (as shown in Fig. 6), the influence degree of the air supply flow is larger significantly, and the position close to the air supply port has a larger SVE4, while the position far from the air supply inlet is smaller. The SVE4 value of the working zone reaches 0.6-0.9, which is apparently higher than the air supply effect of the MAV system, and is not conducive to the small range control of the indoor environment. When there are pollutants or dust in the supply air, compared with MV system, MAV has advantages to ensure the health of human settlements.

3.2 Scene adaptability

Fig. 7 shows the comparison of average temperature and velocity at different spatial heights under different scenarios. The results show that the average temperature rises with the increase of room height.

The velocity curves of four scenarios with MV (white curve) are relatively consistent, as a novel ventilation strategy, MAV can adapt to various scenarios and complete the construction of different velocity fields by changing the vent schemes. The results show that this MV system with four vents has poor response ability to different scenarios, while MAV can be adjusted according to the needs of
different scenarios, indicating that MAV has the advantages of flexibility and adaptability.

Fig. 7. Temperature and velocity distribution at different heights under four scenarios.

3.3 Synergistic adjustment of dynamic airflow

No matter MV or MAV system, for some specific positions, sometimes it is unavoidable for people to sit under the vents and be directly blown by the form of downward air supply, so there is room for improving the thermal comfort. Existed studies have proved that one approach is to create transient thermal environment [2]. Several forms of dynamic airflow include: dynamic personalized air supply, pulsating air supply, intermittent air supply, wearable device air supply [3]. In this study, it is assumed that a new type of air supply generator can be installed to the terminals to generate rectangular wave function airflow. In the simulation, the boundary type of the inlet is set as the velocity inlet where the velocity changes with time, and the boundary conditions are set by UDF function. The period was set to 1 min. The simulated ventilation time is 2 min. Velocity changes periodically at high speed of 1.2 m/s and low speed of 0.4 m/s.

Fig. 8 shows the comparison of PMV-PPD results under constant and pulsating air supply conditions. Four positions in front of the person and on the right side of the person under the diffusers with blowing risks are selected as objects. The results reveal that compared with steady mode, the PMV and PPD of these positions are improved. It can not only save air volume, but also improve the thermal comfort level of the human body.

Fig. 8. Comparisons of PMV-PPD results under steady and pulsating air supply.

4 Conclusions

Through this study, MAV system not only has strong adaptability to daily scenarios, but also makes progress in the zoning division and human thermal comfort. For depth adjustment, MAV can also be combined with dynamic airflow control. For buildings with multi-scene demands, the application of MAV system can indeed improve the indoor thermal environment.

References

1. 小林光，村上周三，加藤信介，不完全混合室内における局所領域の換気効率の同定に関する研究（その1）室内における空調吹出口と排気口の势力範囲の同定，日本建築学会大会学術講演梗概集，pp.539-540, 1992年08月（1992）