Air Distribution Simulation of Natural Ventilation in Dormitory

Jingtao Wu[1, a], Jun Wang[1] and Zhu Cheng[2]

[1]School of Aeronautic Science and Engineering, Beijing University of Aeronautics and Astronautics, Beijing 100191, China;

[2]China Aircraft Strength Research Institute, Xi'an 710065, China

[a]13468606195@163.com

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Abstract. In this paper, physical and mathematical model are set up by using the computational fluid dynamics (CFD) technology in a graduate student dormitory. Air distribution simulation is conducted for door and window on the door during opening and closing periods on the natural ventilation conditions of v=1m/s and v=2m/s. It can be concluded that when v=1m/s for natural ventilation, it can meet the requirements of ventilation in the dormitory and when v=2m/s for natural ventilation, the draft sensation is enhanced, causing uncomfortable issues. It is suggested that in order to keep the air circulate, open the window on the door for a long time.

1. Introduction

The dormitory is the main place for the students to learn and rest. Compared with the office building, indoor air flow and pollutant emission for dormitory are very different. However, people pay less attention to inside air distribution, thermal comfort and indoor air quality of the dormitory. Dormitory is very important for students and some students spend two-thirds of the time staying in the dormitory, so a good dormitory environment can improve learning efficiency, sleep quality. Good ventilation can enhance comfort of students and improve students' health.

Computational Fluid Dynamics is the CFD for short. CFD technology is based on the navier-stokes equation, which uses a variety of turbulence models, finite element method or finite volume method to discretized process for control equations. It also combines with the grid generation technology of fluid flow and simulation technology in the heat transfer processes[1]. With the development of computer technology, CFD technology is mature and so far it has been widely used in all kinds of flow and heat transfer engineering[2-4].

In this paper, by using CFD software under different wind speed of a graduate student dormitory and the different conditions for the door and window on the door, air distribution condition was simulated and analyzed.

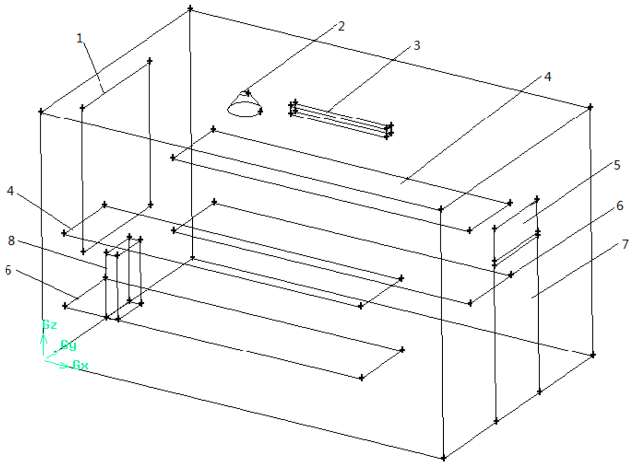
2. Numerical simulation

2.1 The physical model

Simulation object is a graduate student dormitory during the summer. Its structure size is shown in Table 1. The dormitory is a standard room with 4 beds. Each table is under its bed. There are a set of radiators, a lamp for public lighting and a fan in the dormitory. In order to simplify the model, no other objects are in the room and the influence of the dormitory corridor is not considered. When the door and window on the door are in different open situations, different airflow movement situation is simulated under different wind speeds to get the air distribution in the dormitory. In order to simulate the airflow distribution of velocity field and pressure field accurately, the three-dimensional modeling is used in this paper, the model was built according to the proportion of 1:1. Physical model is shown in Figure 1.

Tab.1 Building structure size of the dormitory

Model name	Size of the dormitory	Door	Window on the door	External window	Bed
Size（m）	5.40×3.30×3.10	2.00×0.95	0.95×0.40	1.80×1.50	2.00×0.90
				1.0 meter from the ground	1.65 meters from the ground



1-External window; 2-Fan; 3-Lamp; 4-bed; 5-door; 6-desk; 7-door; 8-radiator

Fig. 1 Physical model

2.2 Mathematical model

Simulation of air flow in a dormitory is steady flow and the air was viewed as incompressible fluid. The control equation is as follows:

$$\frac{\partial \mathrm{U}_x}{\partial x}+\frac{\partial U_y}{\partial y}+\frac{\partial U_z}{\partial z}=0 \qquad (1)$$

$$div(\rho U_x U)=-\frac{\partial p}{\partial x}+div(gradU_x)+S_{U_x} \qquad (2)$$

$$div(\rho U_y U)=-\frac{\partial p}{\partial y}+div(gradU_y)+S_{Uy} \qquad (3)$$

$$div(\rho U_z U)=-\frac{\partial p}{\partial z}+div(gradU_z)+S_{U_z} \qquad (4)$$

Where:

Ux, Uy, Uz are the three directions of air flow rate respectively;

S_{U_x}， S_{U_y}， S_{U_z} are generalized source term of the three momentum equations.

Turbulence model uses the indoor zero equation model:

$$\mu_t = 0.03874\rho \mathrm{U}L \qquad (5)$$

Where:

L is defined as the distance from the nearest wall.

Boundary condition of the model is assumed to be: the initial temperature for 28℃, close to the sunny side of the room wall for 33℃ and the rest of the wall for 28℃. The wind blows into the room from the window. The wind speed is 1m/s and supply air temperature is 25℃. Mathematical model uses zero equation, which is used to simulate the natural convection and mixed convection. The discrete equation of the finite volume method is adopted. The natural convection uses first-order windward scheme, mixed convection second-order windward scheme, and velocity coupled pressure SIMPLE algorithm. This model has a lot of advantages such as a high precision, less time-consuming, fast convergence rate[5].

3. The simulation results and evaluation analysis

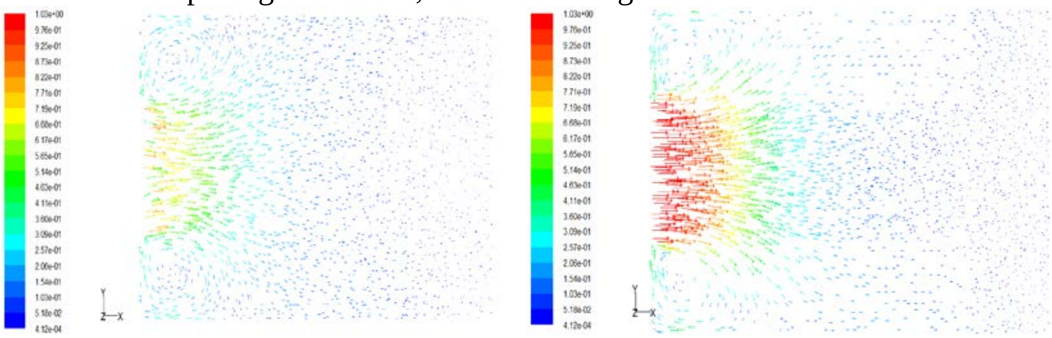
In this paper, by simulating the external window in the different wind speed conditions, door, the influence of window on the door and door opening status on indoor air distribution was analyzed with eight kinds of circumstances, as shown in Table 2.

Tab. 2 Opening states of window on the door and door with different air velocities

States	Opening states Velocity	Window on the door	Door
1	v=1m/s	closed	closed
2	v=1m/s	open	closed
3	v=1m/s	closed	open
4	v=1m/s	open	open
5	v=2m/s	closed	closed
6	v=2m/s	open	closed
7	v=2m/s	closed	open
8	v=2m/s	open	open

Two typical planes were selected in the analysis of simulation result. The one is Z=1.0m, which is the average height when the students study before the desk. This plane can be seen as a typical plane for students studying area. The other one is Z=1.65m,which is height of students sleeping on the bed by measuring the actual distance. By choosing this plane can truly reflect the air distribution when students rest in the dormitory.

Due to limited space, this paper selected part of simulation diagrams for reference only. By simulation calculation for the model, wind velocity vector diagram, velocity distribution cloud diagram, pressure distribution cloud diagram can be obtained when the door and window on the door were in different opening conditions, as shown in Figure 2.

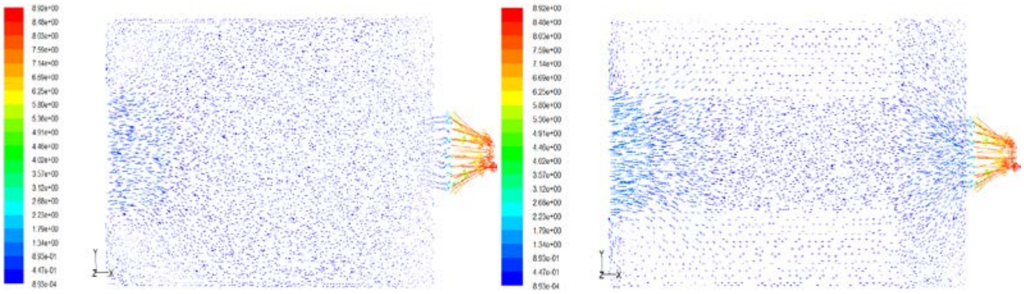


（a）Z=1.0m section （b）Z=1.65m section

Fig. 2 Velocity vector diagram of state 1

From Figure2, it can be seen that when the wind speed of the external window is 1m/s and door and window on the door remain closed, in the section of Z=1.0 m the airflow appears linear motion. When the airflow touches the wall, the diffusive motion moves to both sides. In the distance near the windows (0<x<1), the vortex appears on both sides. The wind speed of two beds away from the window is low.

In order to improve the indoor air distribution condition, the window on the door in the dormitory turns open. The simulation results are shown in Figure 3.

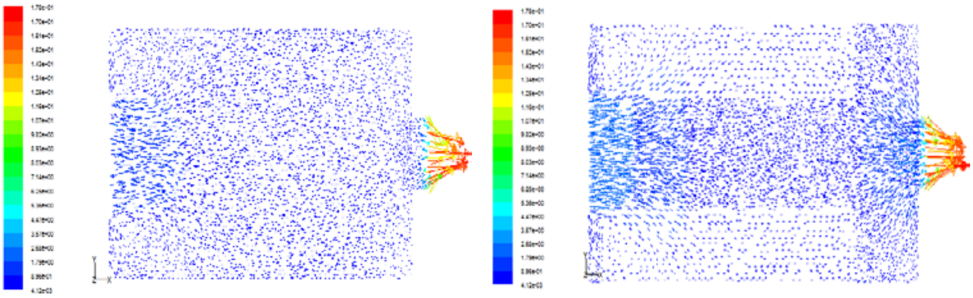


（a）Z=1.0m section （b）Z=1.65m section

Fig. 3 Velocity vector diagram of state 2

As can be seen in the figure, when the wind speed of external window is 1m/s, door still remains closed and window on the door turns open, airflow velocity and pressure have little change in the section of Z=1m. Because the window on the door is 2m from the ground which is far away from the Z=1m plane, opening the window on the door has little influence on the air distribution in the section of Z=1m. However, in the plane of the Z=1.65m, air flows into the dormitory from the window and moves to the direction of the door forming the convection. The airflow diffusion speed is larger than that of the closed window. On the upper part of the air also produced a power, resulting that the range of fresh air in the whole room was substantially larger than that of the closed window on the door.

In order to research the influence of the wind speed of external window on air distribution in the dormitory, the wind speed of external window is set to 2m/s and the state 6 was simulated. The simulation result is shown in Figure 4.



（a）Z=1.0m section （b）Z=1.65m section

Fig. 4 Velocity vector diagram of state 6

We can see from the picture above, when the wind speed of external window is 2m/s and the window on the door turns open, airflow disturbances increases in Z=1m and Z=1.65m section and the velocity vortex becomes more obvious. At the same time, the air velocity near the window on the door also increases accordingly.

Personnel activity area is about in the range of 1<X<4(m). In order to further analyze air distribution situation under different states within the scope of personnel activities. The comparison was made in the following aspects:

(1) Compare state 1 with state 2, the simulation results are shown in Figure 5.

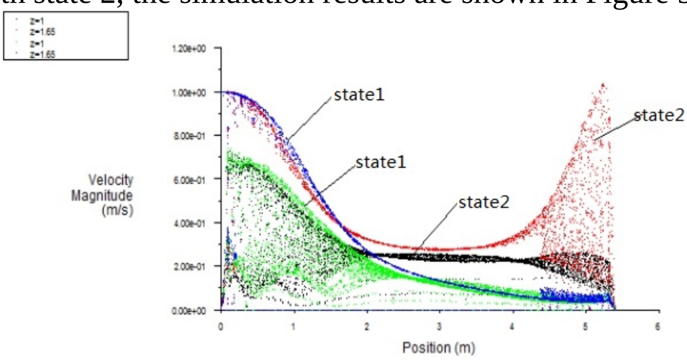


Fig. 5 State 1 and 2 speed distribution in different sections

According to the simulation results, when the door remains closed, the opening and closed states of window on the door had obvious change in the air distribution of Z=1.65 section. At X = 5.4 m section, speed increased from 0.05 m/s to about 1 m/s. But the air distribution change of the Z = 1.0m section was not obvious. The speed increased from 0.05 m/s to 0.25 m/s. The reason is that the window on the door is 2m above the ground and its area is lesser. Therefore the air distribution of the Z=1.0 section changes little. Within the scope of human activities and in the Z=1.0m section and 3<X<4(m), wind speed is less than 0.1m/s, the personnel within this activity area receive less outdoor fresh air. At Z=1.65 section, the wind speed is about between 0.3 and 0.5 m/s, which satisfies the requirement of the human body comfort.

(2) Compare state 1 with state 3, the simulation results are shown in Figure 6.

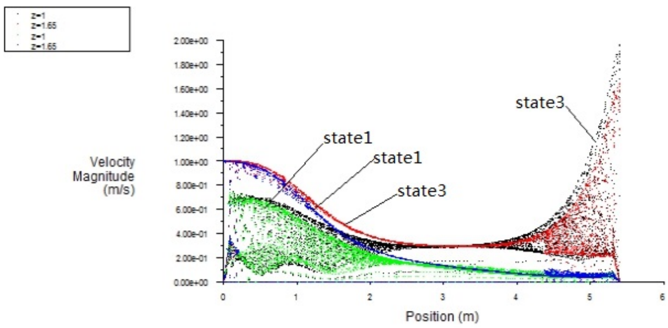


Fig. 6 State 1 and 3 speed distribution in different sections

According to the simulation results, when the window on the door remains closed, the opening and closed states of door had obvious change in the air distribution of Z=1.65 section and Z=1.0 section. At Z=1.0m section, the maximum speed reached 1.9m/s. At Z=1.65m section, the maximum speed reached 1.6m/s. But within the scope of human activities, at 1<X<1.5(m), the air speed is between 0.5 m/s and 0.8 m/s. In this activity personnel feel a sense of blowing and in other area the wind speed keeps about 0.3m/s, which can meet requirement of human body comfort.

(3) Compare state 3 with state 4, the simulation results are shown in Figure 7.

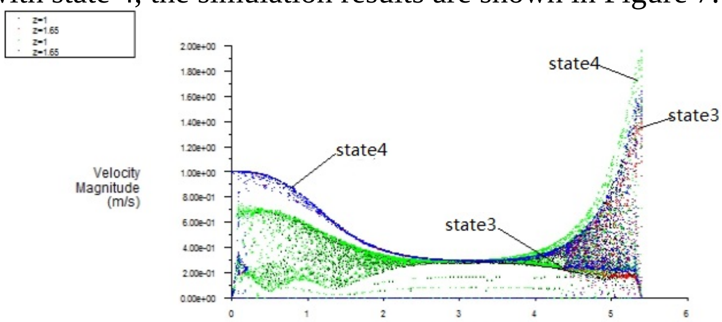


Fig. 7 State 3 and 4 speed distribution in different sections

According to the simulation results, when the door remains open, the opening and closed states of window on the door had obvious change in the air distribution of Z=1.65 section and Z=1.0 section. At Z=1.0m section, the maximum speed reached about 2.0 m/s. At Z=1.65m section, the maximum speed reached 1.6 m/s. In addition, when the door is open, the opening and closed states of window on the door had little change in the air distribution within personnel activity area.

(4) Compare state 2 with state 6, the simulation results are shown in Figure 8.

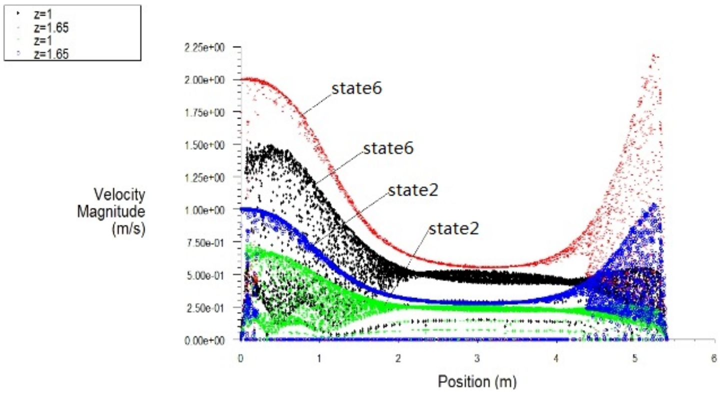


Fig. 8 State 2 and 6 speed distribution in different sections

According to the simulation results, when the door remains closed and window on the door keeps open, when the wind speed at the external window reaches 2 m/s, air velocity has increased at 1<X<4 (m) area. At Z=1.65 section, the minimum speed increased from 0.35m/s to 0.65 m/s. At Z=1.0 section, the minimum speed increased from 0.25 m/s to 0.6 m/s. Therefore, it will bring certain blowing sense to personnel in the dormitory, resulting in uncomfortableness.

4. Summary

The conclusions are as follows:

(1) the opening and closed states of the door and window on the door in the dormitory have a great influence on the air distribution.

(2) when the door and window on the door are open at the same time, the air distribution of window on the door has a little influence on the personnel activity area. But when the door is closed, the air distribution of window on the door has a great influence on the bed Z=1.65m section. Therefore, we can not ignore the influence of window on the door in the dormitory.

(3) the opening and closed states of the window on the door have little change on the air distribution at Z=1.0 section. But it plays a very important role in the air distribution at Z=1.65 section. Therefore when you rest on the bed, we suggest opening the window on the door for a long time to maintain good air quality.

(4) when you learn in the dormitory, we suggest opening the door to maintain good air distribution on the surface of the desk.

(5) when the wind speed at external window is 1 m/s, it can satisfy the requirement of the human body comfort. But when the wind speed increases to 2 m/s, although the overall air distribution improved in the dormitory, but wind speed is slightly faster within human activity area, which brings certain blowing sense to personnel in the dormitory and results in uncomfortableness.

References

[1] Wang Fu-jun. Computational fluid dynamics analysis-CFD software principle and application [M]. Beijing: tsinghua university press, 2004

[2] Sun Qing-kuan. CFD simulation technology in the application of air conditioning room temperature field research [J]. Journal of hvac, (2002), No. 2, p. 95-98

[3] Chow W K. Numerical studies of airflows induced by mechanical ventilation and air-conditioning systems[J]. Applied Energy, Vol 68 (2001), No. 2, p. 135-159

[4] Chen Q, Srebric J. Application of CFD tools for indoor and outdoor environment design[J]. Architectural Science, (2001), No. 1, p. 32-45

[5] Sun Sheng, Li Jie-lin. Numerical simulation and evaluation of indoor air quality[J]. Environmental science and management, (2007), No. 11, p. 66-68