Numerical study on natural ventilation of classroom in Chaobei area of China

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Abstract. Natural ventilation is one of the main method of passive cooling for buildings, which is widely used in the Chinese colleges and universities classroom during the transitional seasons. To optimize the number of doors and windows in the classroom, the CFD (i.e. Computer Fluid Dynamics) method is used to study the wind speed effect on the flow distribution under the varying of windows and doors. The results show that with the number of people increasing, the indoor flow changes from constant to turbulent flow. This method and results can be used for the building design in the colleges and universities classroom.

1. Introduction
The indoor environment which plays an important role in building energy conservation provides guarantee for human comfort. In the transitional seasons, natural ventilation is widely used to classrooms in China, meet the requirements of human comfort to reduce HVAC energy consumption. In China, the emphasis on the building wind environment is still insufficient, and at present, increased the design of building wind environment in urban planning and design[1]. Due to the uncontrollable of natural ventilation, most of the research scholars did study mainly through CFD (i.e. Computer Fluid Dynamics) simulations and wind tunnel experiments.

Jiang and Chen [2] studied stack ventilation using two experimental methods: real experimental test and CFD. Camille et al.[3] described the importance of natural ventilation by investigating, and indicated that natural ventilation is not only an effective energy-saving measure, but also an effective improvement of IAQ(indoor air quality). Lin et al.[4] field measurements on thermal stratification and cooling potential of natural ventilation in high and large spaces. It was found that temperature increases as a linear function of height in the range of 0.1-0.24 °C /m. Papakonstaitino [5] established a single-side ventilated building model, and analyzed the influence of the ventilation opening area on the indoor airflow pattern. Lu et al. [6-7] studied the influence of the indoor natural ventilation by change the location, size, and opening angle of the window, and identified the optimal configuration. Zhang et al. [8] established two room models. The indoor physical model simulated the distribution of the indoor air field, and proposed that the positions of the components such as doors and windows would cause changes in the indoor air environment, affecting indoor thermal comfort performances. At present, there are few studies of classroom in universities under nature ventilation in the transition seasons, and most of these researches had analyzed the air age and ventilation effect, and in this condition, few studies have been conducted on the ventilation of increased heat sources. This work
mainly analyzes from these aspects in universities’ classroom and lays a foundation for the research on the energy saving effect and human comfort of natural ventilation.

2. CFD simulation object and method

2.1. CFD simulation method

Classrooms are places where students stay for a long time in college, and mainly use natural ventilation. Wind environment is an important part of creating a healthy and comfortable campus. CFD method which is attracted people's attention because of its powerful functions of simulating complex flow phenomena, man-machine dialogue interface operation and clear flow field display, is used in this study. Although there are many kinds software of CFD, we used Airpak in this work. The structure is basically the same, which consists of three modules: Pre-processor, Solver and Post-processor. The functions of each module are described as follows. Pre-processor: Create a geometric model describing the problem (or be built and imported by other software such as CAD), determine control equations (such as N-S equation, turbulence model), discrete methods, calculation methods (such as SIMPLE, MAC), input necessary parameters (such as initial conditions, boundary conditions, physical parameters etc.) and form a mesh. Solver: The core of CFD, solves the system established by the pre-processor and outputs the calculation results. Post-processor: Visualization results and animation processing of calculated parameters (such as temperature field, velocity field and pressure field etc.).

2.2. Model selection

According to the climatic conditions of China's Chaobei area, where is located in the hot summer and cold winter zone. Easterly is the dominant wind direction in the transitional seasons, and the average speed is 2.47m/s [9]. According to the classroom dimensions of a university in Chaobei area, the model size (length, width, height) is 15 m (x-axis) × 8 m (z-axis) × 4 m (y-axis). In this paper, Steady-state simulation is used study indoor wind speed. The surrounding structures of the room such as walls, doors and windows are set as thermal insulation. The influence of external climatic conditions is ignored. And the initial temperature is adopted as the default value.

2.3. Simulation scheme

The teaching building generally has 5 floors, and the height of each floor is 4m. 1st, 3rd and 5th layers of the model are selected for analysis. According to the physical properties of outdoor underlying surface, the characteristics of outdoor air flow and for convenience of statistics, we set the initial wind velocities to 1 m/s, 1.25 m/s and 1.37 m/s. As vertical wind speed gradient exists, the wind speed is set to increase with height. We made a qualitative analysis to study the change of wind speed by changing the number of doors and windows, and increasing indoor people number (i.e. heat source). A total of 36 working conditions are simulated for the same model in this paper. As shown in 2.3.1, the doors number is one or two, and the number of windows is 8 or 4. The wind will blow in through the window and out of the door. There are four kinds of heat sources: no heat source, 40 people, 80 people and 120 people.

2.3.1. Natural ventilation without heat source. (1) Case 1: One door and all 8 windows open, the schematic of the model is shown in Figure 1. We defined this case as A. and Table 1 shows the model details for case 1.

(2) Case 2: Two doors and all 8 windows open, the schematic of the model is shown in Figure 2. We defined this case as B. Table 1 shows the model details for case 2.

(3) Case 3: changing the numbers of windows, 4 windows and 2 doors open, the schematic of the model is shown in Figure 3. We defined this case as C. Table 1 shows the model details for case 3.
2.3.2. Natural ventilation with heat source. Divided into three cases, 40, 80, 120 people are evenly distributed indoors. Each person's size is 1.74 m × 0.3 m × 0.2 m. The body heat dissipation is automatically set by Airpak, which is based on the body metabolism and the body surface areas. Table 2 shows the Body heat dissipation.

![Figure 1: 15 m × 8 m × 4 m.](image)

| Model | Name | Size (m²) | Number |
|-------|------|-----------|--------|
| Case 1 | door | 1.3 × 2.2 | 1 |
|      | window | 1.6 × 2.3 | 8 |
| Case 2 | door | 1.3 × 2.2 | 2 |
|      | window | 1.6 × 2.3 | 8 |
| Case 3 | door | 1.3 × 2.2 | 2 |
|      | window | 1.6 × 2.3 | 4 |

![Figure 2. Case 2: 15 m × 8 m × 4 m.](image)

![Figure 3. Case 3: 15 m × 8 m × 4 m.](image)

Table 2. Body heat dissipation.

| No. | Number of people (104.67 W/人) | Total heat dissipation (W) |
|-----|--------------------------------|---------------------------|
| 1   | 40                             | 4186.8                    |
| 2   | 80                             | 8373.6                    |
| 3   | 120                            | 12560.4                   |

3. Simulation results and analysis

3.1. Analysis of simulation results when the wind speed is 1.37 m/s (floor 5).

Figure 4 shows the speed streamline of floor 5, divided into two cases—without heat and with 40 person. As shown in Figure 5 and Table 3, when one door open, maximum wind is around doors. The speed
decreases when touching the door for the boundary layer effect. As shown in Figure 6, the minimum wind speed at the door boundary is 0m/s. Comparing B and C, the larger the window opening area is, the higher the wind speed is. Increased heat source, the average wind speed through the door has increased. Contrast C1, C2, C3, increased the heat source, the increasing trend of the maximum wind speed at the outlet was not obvious. The average wind speed changed significantly when the person (heat source) arranged in the front of the door. At the same time, the average wind speed increased when the person (heat source) faced the door, but total mass flow through door decreased. Because of the personnel, increased the barrier area, otherwise, there are gaps between the people, which reduced the cross section of fluid flow, increased the wind speed in the air. Found in Figure 4, when increased the personnel, the wind speed of the personnel distribution area is obviously decreased, compared with that no personnel.

**Figure. 4** The speed streamline(floor 5).
According to the change of indoor air distribution, we found in Figure 5 when one door open, minimum wind speed at the same side with door, where the air age is the largest. Based on air distribution, analysis of ABC cases, we found that B which open 2 doors and 8 windows is the best on ventilation, the speed streamline is stable, and the air age is youngest. A1B1C1 shown the wind speed deceased in personnel area, and partial turbulence of speed streamline. Compared CC1, the wind speed decreased significantly in the middle area.

Table 3. Values of the position of the door passing through the base wind speed of 1.37m/s.

|       | Max speed through door (m/s) | min speed through door (m/s) | Mean speed (m/s) | Total mass flow through door (kg/s) | Total volume flow through door (m3/s) |
|-------|-----------------------------|-------------------------------|-----------------|-------------------------------------|--------------------------------------|
| A     | 17.348                      | 0                             | 9.621           | -48.630                             | -39.698                              |
| A1    | 17.618                      | 0                             | 10.690          | -48.638                             | -39.700                              |
| B(doors 1) | 8.736                      | 0                             | 5.056           | -24.270                             | -19.810                              |
| B1(doors 1) | 8.839                      | 0                             | 5.337           | -24.276                             | -19.817                              |
| C(doors 1) | 4.372                      | 0                             | 2.533           | -12.140                             | -12.18                               |
| C1(doors 1, nobody) | 4.365                      | 0                             | 2.651           | -12.159                             | -9.926                               |
| C1(doors 2, nobody) | 4.365                      | 0                             | 2.651           | -12.160                             | -9.926                               |
| C2(doors 1, with person) | 4.516                      | 0                             | 3.192           | -11.970                             | -9.771                               |
| C2(doors 2, nobody) | 4.398                      | 0                             | 2.699           | -12.350                             | -10.081                              |
| C3(doors 1, with person) | 4.573                      | 0                             | 3.237           | -12.144                             | -9.913                               |
| C3(doors 2, with person) | 4.597                      | 0                             | 3.196           | -12.175                             | -9.938                               |

*C2 change the numbers of windows With 80 person
*C3 change the numbers of windows With 120 person

Through the comparative analysis of ABC, we found that the value of Total volume flow is changed when changing the number of doors and windows. When the number of classroom doors is reduced by one, the exit area was reduced by half, and the total volume flow is doubled. Similarly, when the number of the same window is reduced by half, the enter area is reduced by half, total mass flow and total volume flow are also reduced by half. As shown in the Figure 7, the speed contour for the section at z =0 m, the wind speed in the middle position is significantly reduced. With the number of people increasing, the indoor flow changes from constant current to turbulent flow.

Draft sense is one of the problems that the human is not satisfied with the external environment, which mean that we does not want lowering the temperature of the body part. In general, the minimum
wind speed that cause uncomfortable human body is 0.25m/s[10]. It is not difficult to find out from Figure 7, when no personnel in the room, the wind speed is basically over 0.25m/s except few points. Increase personnel, the speed passing through the personnel is about 0.12m/s-0.18m/s at 40 person, about 0.10m/s-0.19m/s at 80 person, and about 0.8m/s-0.15m/s at 120 people. In these three cases, the wind speed is all less than 0.25m/s. Blowing here helps to improve thermal comfort. At the same time, when distribute 80 or 120 persons those people near the door may feel uncomfortable due to the upper side high speed wind. At the same time, as the number of people increases, the wind speed in the upper part of the room increases significantly due to the hot pressing.

![Figure 7. The speed contour for the section at z = 0 m.](image)

3.2. Analysis of simulation results at wind speed of 1.25m/s (floor 3)
Given x=-7.5m, y=1.5m, that is mean the height is 1.5m, and on the center axis of the room of z-axis, divided into four cases: without heat one door open(a), with 80 men one door open, without heat two doors open, with 80 men two doors open. All the cases open 8windows. Figure 8 shown the wind speed by changing different z coordinate points along the x direction(z=-3,-2,-1,0,1,2,3). When there is no heat source, the wind speed was regularity at each point in the classroom. Increased the heat source, the fluctuation of wind speed is larger. The minimum wind speed is at the center point. The closer to the door, the higher the wind speed. To observe more obviously, we choose 9 points 1m away from the doors(z=3.0-z=3.8), At the position of z=3.6, where is 40cm from the door, the slope of the wind speed increased, and the wind speed is increasing obviously. Its shown in Figure 9.

The Relationship between the number of doors and windows and wind speed(floor 1)
Figure 10 shown us when opened one door, the internal and external air to be exchanged under pressure difference, and the door endured all the flow pressure, resulting the wind speed reached nearly ten meters per second through the door. In Figure 10(a), normal operation will not be possible near this door. Due to this condition, it is necessary to diffuse the pressure. As shown in Figure 10(b), the above problems are slightly alleviated by open the other door, but the convective motion formed by the two doors still cannot diffuse the pressure of high wind speed. By adjusting the number of windows in Figure 10(c), the air flow rate returns to normal, and the above problem is solved.
Figure 8 Variation of speed with x at given coordinate (x, y, z) for cases.

Figure 9. Variation of speed with the different distances to the door of two cases.

Figure 10. The speed contour for the section at y = 1.5m.
4. Conclusions
Through the simulation study of this paper, we can draw the following conclusions:

1. When the number of classroom doors is reduced by one, the exit area is reduced by half, and the total volume flow is doubled. Similarly, when the number of the windows is reduced by half, the enter area is reduced by half, total mass flow and total volume flow are also reduced by half. With the number of people increasing, the indoor flow changes from constant current to turbulent flow.

2. When the number of people reaches to 80-120, those people near the door may feel uncomfortable due to the high speed wind upper side. At the same time, as the number of people increases, the wind speed in the upper part of the room increases significantly.

3. If only one door open, the people near the door may be affected, and if two doors open, then the convention formed to reduce the wind speed. Adjusting the number of windows, opening half of the windows will ensure the internal air flows normally, which means the indoor wind speed can meet the requirement for making the people feel comfortable.

4. The larger the opening area of the window, the higher the exit wind speed, but in this case, the effect of solar radiation is not considered. The combined effects of hot pressing and wind pressure will be further considered, and further research of verification will be carried out through experiments.

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