Simulation Analysis and Evaluation of Wind Environment for a Teaching Building in a Certain Region

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Abstract

With the implementation of Assessment Standard for Green Building, the construction of green campuses has become a pivotal benchmark in modern Chinese educational infrastructure development. For teaching buildings, due to the dense student population during class hours, ventilation conditions have a significant impact on the environment and physical well-being of both teachers and students, while also influencing teaching quality. This study focuses on a teaching building in Pu'er and employs Computational Fluid Dynamics (CFD) to simulate variations of indoor and outdoor wind environments with different seasons. Subsequently, an assessment is conducted on the wind environment of the building based on GB/T50378-2019 "Assessment Standard for Green Building".

Keywords

Wind Environment; CFD; Green Building Evaluation.

1. Introduction

Green buildings strive to establish a symbiotic relationship between architectural design and the natural environment by implementing environmentally sustainable and energy-efficient methodologies. Exploration and research on green buildings at an international level commenced in the 1960s [1]. During the 1990s, the concept of 'green campuses' was implemented in developed countries including Canada, America, the United Kingdom, and Japan. The world's first 'green' college science building demonstrated modern national-level low-pollution construction techniques [2]. During the same period, China began promoting the basic strategy of 'sustainable development'. In 1998, Tsinghua University became the pioneer of implementing green campus construction in Chinese universities [3]. The campus buildings, driven by the promotion of assessment standard for green building, can offer students a secure and conducive learning environment, promoting their physical and mental well-being [4].

Teaching buildings are crucial spaces for student learning. A comfortable learning environment is essential for improving students' learning efficiency and teachers' instructional quality. Classroom comfort largely depends on the regulation of indoor temperature, humidity, and air quality. Ventilation technology is a key means of adjusting these three indicators. Before the advent of mechanical heating, ventilation, and air conditioning (HVAC), natural ventilation was the primary method for regulating airflow in buildings. The advancement of mechanical HVAC technology has facilitated the automatic regulation of temperature and humidity, leading to the creation of more comfortable living and working environments. However, it has increased building operational energy consumption [5] and exacerbated environmental deterioration.

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In this paper, presents a case study of the teaching building in low latitude and high altitude region, simulating and analyzing its indoor and outdoor wind environment. Exploring appropriately placed windows to achieve natural ventilation in buildings, thereby reducing the need for mechanical ventilation and lowering building operational energy consumption. Additionally, wind environment of the building is evaluates in accordance with green building standards.

2. Modeling

The building is located in Pu'er, Yunnan Province. The region maintains a temperate climate with no frost throughout the year. The primary function of the building is as an educational facility, consisting of five above-ground floors. The first floor has a height measurement of 4.5 meters, while floors two to five each have a height measurement of 3.9 meters. Fig. 1 shows the single building model. It is marked as A in the building group, and the general building drawing model is shown in Fig. 2.

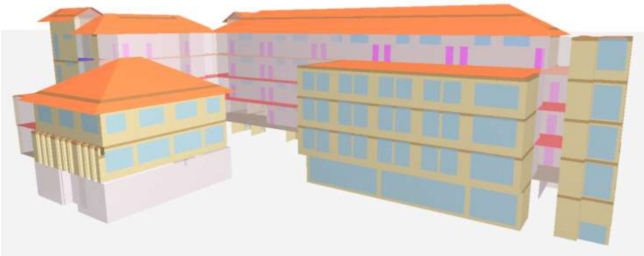


Fig. 1 Building single model southeast axis perspective drawing

The main focus of our research is the teaching block, for which we have developed a comprehensive model that includes meticulously designed doors, windows, and other ventilation openings, as shown in Fig. 1. As depicted in Fig. 2, the remaining buildings in the overall site plan are simplified into cuboid blocks while disregarding doors and windows. However, the actual dimensions of the original structures are maintained. The overall layout of the building is oriented from north to south, strategically aligning with the natural wind direction and maximizing the utilization of wind resources. The wind pressure and velocity surrounding the teaching block, derived from outdoor wind environment simulations, will be utilized as input parameters for indoor ventilation simulation calculations.

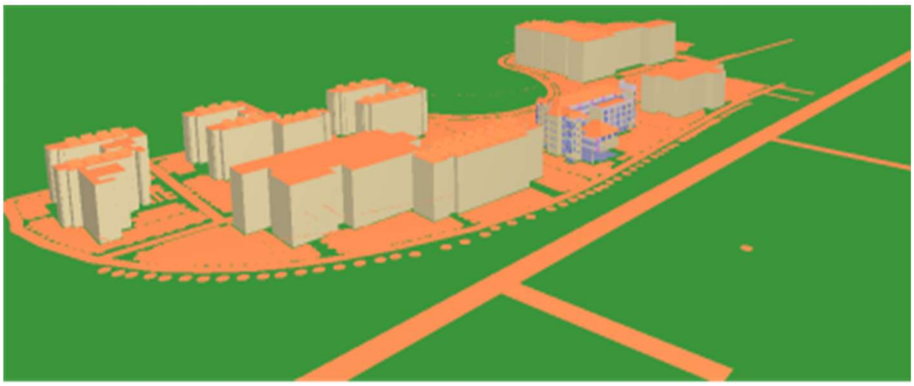


Fig. 2 Overall building model

3. Computational Principles

3.1 Turbulence Model

Turbulence models reflect the state of fluid flow. In computational fluid dynamics simulations, the selection of suitable turbulence models is crucial for accurately predicting flow field values in various fluid flows. This project use the k-ε turbulence model in CFD for outdoor and indoor flow field calculations, in accordance with the standards set in the 'Technical Guidelines for Green Building Evaluation'. The governing equations for this computational method are as follows,

$$\frac{\partial(\rho\varphi)}{\partial t} + div(\rho U\varphi) = div(\Gamma_{\varphi} grad) + S_{\varphi} \quad (1)$$

In equation (1), φ can represent physical quantities such as velocity, turbulent kinetic energy, turbulence dissipation rate, and temperature.

3.2 Boundary Conditions

The first boundary condition for the outdoor environment is the inlet and outlet boundary conditions. The inlet boundary condition is the inlet velocity gradient. It is described by

$$v = v_{\mathrm{R}}(z / z_R)^{\alpha} \quad (2)$$

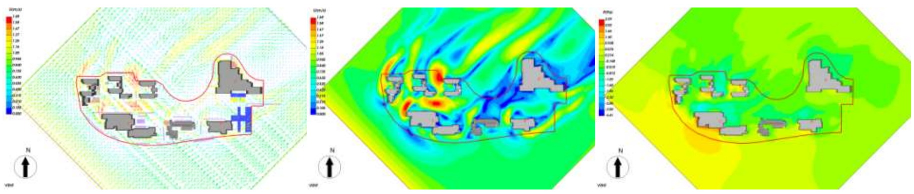
In equation (2), v and z represent the average wind speed and height at any point; v_{R} and z_R are the average wind speed and standard height value at the reference height. The 'Code for Load Design of Building Structures' GB50009-2012 stipulates that the standard height for natural wind fields is 10m, and this average wind speed corresponds to the inlet wind setting value. α is the ground roughness index, which is 0.14 for this project. The outlet boundary condition for this project uses free outflow.

The second boundary condition for the outdoor environment is the wall boundary condition. The two side boundaries and the top boundary of the wind field are set as slip walls, meaning air flow is not affected by wall friction. The ground boundary of the wind field is set as a no-slip wall, where air flow is affected by ground friction.

For the indoor environment boundary conditions, both the inlet and outlet windows use pressure boundary conditions.

4. Simulation and Analysis of Outdoor Wind Environment

4.1 Simulation and Analysis of Outdoor Wind Environment in Summer



(a (b (c

Fig. 3 Outdoor wind environment simulation analysis at 1.5m height in summer

According to the requirements of the "The standard of the measurement and evaluation for efficiency of building ventilation" JGJ/T 309-2013, we used an inlet boundary wind speed of 1.90m/s and the prevailing wind direction of SW for the summer working conditions of this project as parameters for simulation. Due to surface friction, wind speed decreases closer to the ground. To approximate real conditions, we employed the gradient wind represented by equation (2) at the inlet during simulation analysis. After simulation calculations, we obtained vector diagrams, cloud maps, and wind pressure diagrams of outdoor wind speeds at 1.5m above ground in summer, as shown in Fig. 3(a), 3(b), and 3(c) respectively. From Fig. 3, it can be observed that when natural wind passes over the building

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area, the maximum wind speed is 1.18m/s, which does not exceed 2m/s, and negative pressure forms around the buildings, enabling natural ventilation. This design reduces the use of mechanical ventilation.

4.2 Simulation Analysis of Outdoor Wind Environment in Winter

Similar to the summer conditions, according to the requirements in relevant standards, the inlet wind speed for winter conditions in this project is 2.7m/s, with the main wind direction being WSW, at a height of 1.5m. These values are used as the primary parameters for simulation. The simulation analysis still employs gradient wind as the inlet boundary condition. Fig. 4(a), 4(b), and 4(c) show the simulated outdoor wind velocity vector diagram, wind speed contour map, and wind pressure map at 1.5m height in winter, respectively. From Fig. 4(a) and 4(b), it can be observed that the maximum wind speed around the building in winter is 1.46m/s, which is higher than the maximum wind speed in summer. The wind pressure contour map in Fig. 4(c) indicates that negative pressure is still formed around the building, and it is slightly higher than in summer.

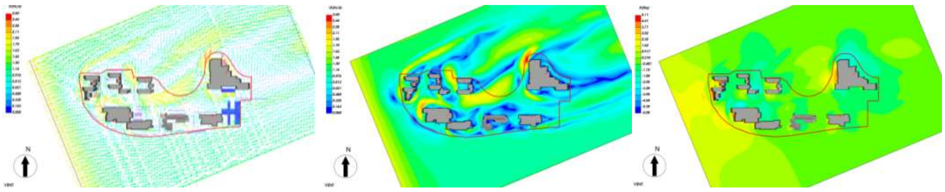
(a) (b) (c)

Fig. 4 Outdoor wind environment simulation analysis at 1.5m height in winter

4.3 Analysis of Green Building Standards for Outdoor Wind Environment

In summer, to achieve a good indoor wind environment, it is essential to have a good outdoor wind environment first. When external windows are closed, the wind pressure on the inner surface of the window is approximately zero. Sufficiently large absolute wind pressure on the outer surface of external windows is essential for ensuring good ventilation effects when they are opened, thus creating a favorable indoor wind environment. Therefore, the "Assessment Standard for Green Building" requires that the wind pressure difference between the inner and outer surfaces of external windows be greater than 0.5Pa, i.e., the absolute value of wind pressure on the outer surface of the closed window should exceed 0.5Pa. In order to effectively utilize natural ventilation for a favorable indoor wind environment during the summer, it is necessary for more than 50% of operable external windows to exhibit a wind pressure difference greater than 0.5Pa between their inner and outer surfaces. In this project, 153 rooms of the studied building (teaching building) have operable external windows with an inner-outer pressure difference greater than 0.5Pa. Accounting for 72.17% of the rooms up to the standard.

The "Assessment Standard for Green Building" stipulates that the area of vortex zones/windless zones in human activity areas should be zero in summer. However, the wind velocity cloud diagram (Fig. 3(b)) simulating summer conditions shows that there are human activity areas around Building A where wind speed is less than 0.2m/s. Therefore, the windless zones in this project do not meet the standard.

The "Assessment Standard for Green Building" stipulates that under winter conditions, except for the first row of buildings facing the wind, the wind pressure difference between the windward and leeward surfaces of buildings should not exceed 5Pa. This is because an excessive wind pressure difference between the windward and leeward surfaces of buildings can lead to excessive cold air infiltration through door and window gaps, increasing indoor thermal load and consequently energy consumption. Thus, the control of wind pressure difference between windward and leeward surfaces needs to be reflected in the wind pressure on the corresponding doors and windows. This project uses an area-weighted method to calculate the wind pressure values for doors and windows on the

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windward and leeward sides of the building. Table 1 shows the wind pressure difference values for each floor and the entire Building A, all of which do not exceed 5Pa, meeting the standard.

Table 1. Average wind pressure difference between windward and leeward sides of building A

Region	Average wind pressure on windward surface(Pa)	Average wind pressure on the leeward side of windows(Pa)	Average wind pressure difference on windward and leeward sides(Pa)
1F	-0.10	-0.56	0.46
2F	-0.38	-0.29	-0.09
3F	0.01	-0.59	0.60
4F	0.01	-0.38	0.39
5F	0.86	-0.54	1.40
Entire Building A	-0.09	-0.45	0.36

5. Indoor Wind Environment Simulation Analysis

Generally, based on the outdoor wind environment simulation results, the less favorable outdoor boundary conditions were selected as the boundary conditions for studying the internal airflow organization of the research object. Through the analysis of 4.2, it is concluded that the most unfavorable ventilation condition is in summer. Therefor, the indoor boundary conditions for this design were the wind pressures at the inlet and outlet windows during summer, and the airflow organization at a height of 1.2m for human activity was simulated. As the building structure and room layout from the second to fourth floors are identical, we chose the first, third and fifth floors as representative for the study. Figs 5-7 show the wind velocity vector diagrams (a) and wind pressure cloud maps (b) for the first, third and fifth floors under summer conditions, respectively.

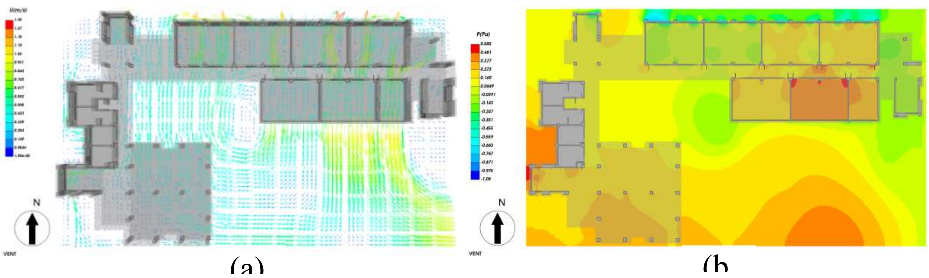

Fig. 5 Indoor wind environment simulation diagram at 1.2m height of the first floor in summer

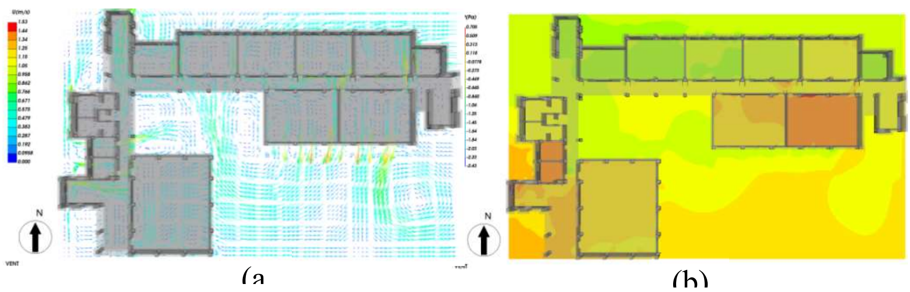

Fig. 6 Indoor wind environment simulation diagram at 1.2m height of the third floor in summer

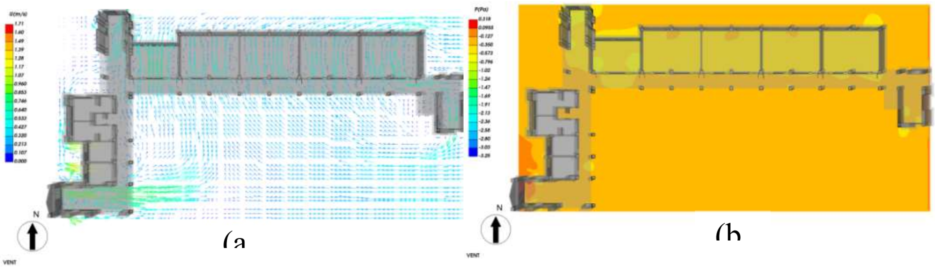

Fig. 7 Indoor wind environment simulation diagram at 1.2m height of the fifth floor in summer

As depicted in Fig. 5, with the exception of the restroom and storage area on the western side lacking airflow due to their absence of windows, all other frequently utilized classrooms and activity rooms exhibit adequate air circulation without any stagnant regions and some degree of wind pressure. Fig. 6 illustrates that the airflow organization in all third floor rooms is optimal. In Fig. 7, the toilet on the fifth floor has fixed glass windows and the storage room has no windows, resulting in no airflow in these areas. Most other functional rooms on this floor face south and west without obstructions, leading to rich airflow patterns. Therefore, the technical measures used in the evaluated rooms of the building A are reasonable. CFD analysis confirms appropriate indoor airflow organization, meeting the requirements of Section 5.1.2 of the "Assessment Standard for Green Building".

Figures 5-7 display wind velocity vectors and pressure contours, indicating a gradual increase in wind speeds as floor levels rise, while remaining below 2m/s. Wind pressure also rises with height, reaching absolute values greater than 0.5Pa but less than 5Pa, meeting the standard.

6. Summary

The energy consumption of ventilation systems in public buildings accounts for a significant proportion of overall building energy consumption. School teaching buildings are crucial spaces where students attend classes and study. Therefore, ventilation in school buildings is particularly important. This paper focuses on a school teaching building in Pu'er, located at a low latitude and high altitude, as the research subject. The outdoor wind environment of the building was simulated using CFD for both winter and summer seasons. Analysis of the simulation results indicates that the outdoor wind environment design of this building up to the requirements of the "Assessment Standard for Green Building" GB/T50378-2019. Furthermore, the indoor wind environment was simulated and analyzed using parameters selected based on calculations of the outdoor wind conditions under the most unfavorable circumstances. The results show that the airflow organization in all evaluated rooms satisfies the requirements of the "Assessment Standard for Green Building" GB/T50378-2019.

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