

# Simulation and Optimization Analysis of Summer Indoor Thermal Environment for School Buildings in Hot Summer and Cold Winter Zone



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**Abstract** Due to the particularity of the function and the use of school buildings, the quality of indoor thermal environment is directly related to the normal development of educational activities and the quality of talent training in schools. So, it is significant to research and improve the indoor thermal environment. In order to understand the present situation of summer indoor thermal environment in school buildings in hot summer and cold winter zone, this paper takes a teaching building in Chengdu as the research object and combines the PHOENICS software to simulate the current situation of indoor thermal environment in summer. And proposed some kind of the energy-saving design strategies such as adopting different types of shading facilities and setting air guide plate. Finally, we analyzed the effect of different optimizations of strategies on the indoor thermal environment of the summer building in the hot summer and cold winter zone.

**Keywords** School buildings · Indoor thermal environment · Simulation analysis · Energy-saving design strategy

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## 1 Introduction

The classroom is the main learning place for students. The environmental quality of the learning space has an important impact on the students' physiology and psychology [1]. Studies have shown that a healthy and comfortable learning environment can promote students' enthusiasm for learning and improve students' learning efficiency [2]. The quality of a classroom environment is closely related to the indoor thermal environment of the classroom. The indoor thermal environment refers to the environmental factors that affect the human body's feeling of heat and cold. These factors mainly include indoor air temperature, air humidity, airflow speed, and radiative heat transfer between the human body and the surrounding environment. A suitable indoor thermal environment refers to the indoor air temperature, humidity, airflow velocity, and ambient thermal radiation, which makes the human body easy to maintain thermal balance and feel comfortable indoor environmental conditions [3]. The most important criterion for evaluating the indoor thermal environment is the human thermal comfort [4]. Overheating or too cold in the classroom can lead to headaches, dizziness, and other discomforts and may even cause illness. The comfort zone recommended by the ASHRAE Standard 55-1992 standard is currently widely used as a measure of thermal comfort. In 1967, Prof. Fanger of Denmark used these data to combine the thermophysical equations of human body heat production and heat dissipation and proposed the thermal comfort equation which is practical now. The calculation method for predicting the average number of votes PMV and the projected unsatisfactory percentage PPD is obtained [5]. The PMV-PPD evaluation system combines six factors as air temperature, air humidity, average radiant temperature, airflow rate, human body metabolic rate, and garment thermal resistance. It has been adopted by the international standard ISO7730.

Some related studies show that in naturally ventilated classrooms, students either adapt to the environment through exposure to the environment for a long time or adapt to the environment by controlling fans, windows, clothing, etc. [6]. However, considering the increasing demands of students for the school's thermal environment and the intensified global energy crisis, using the passive energy-saving design strategies that collect energy through sunshading and daylighting [7], natural ventilation [8, 9] and solar energy [10] to improve the indoor thermal environment of the teaching building have become the choice of more and more architects to minimize the energy consumption and the use of various resources while improving the indoor thermal environment.

Domestic and foreign scholars have also carried out a lot of research on the indoor thermal environment of school buildings. Xi et al. [11] studied the indoor thermal environment and thermal comfort of campus open spaces in the context of subtropical climate. Their research suggests that design elements of the physical environment, such as flooring materials, ground textures, can have a major impact on thermal comfort. Luo et al. [12] studied the indoor thermal environment of a teaching building in Chongqing. The results show that in the high-temperature

classroom environment, students have a corresponding increase in the tolerance of wind speed. Increasing wind speed is an effective measure to improve indoor thermal environment. However, at present, quantitative research on improving the indoor thermal environment of teaching buildings through different design strategies is still insufficient. Therefore, this paper takes a teaching building in Chengdu as a research case and uses CFD to simulate its indoor thermal environment and obtain the indoors' temperature field, wind speed field, and PMV index and analyzed the current situation of indoor thermal environment in summer in details. Based on this, passive energy-saving design strategies such as adopting different types of shading facilities and setting air guide plate are proposed. The conclusions of this paper can provide suggestions and references for the planning and design of the future school and the architectural design of the teaching building.

## **2 Methodology**

### ***2.1 Climate Condition and Building Modeling***

This study uses the standard weather data of Chengdu as an outdoor reference condition. Chengdu is located between  $102^{\circ} 54' - 104^{\circ} 53'$  E longitude and  $30^{\circ} 05' - 31^{\circ} 26'$  N latitude. It is in the hot summer and cold winter zone and belongs to the subtropical humid climate. The daily maximum temperature is from June to August, the temperature is about  $30^{\circ}\text{C}$ , and extreme weather above  $35^{\circ}\text{C}$  may occur. Another distinctive feature of Chengdu's climate is that the air is humid. Therefore, although the temperature is not very high in summer, it is hot and the summer in Chengdu is longer than the wintertime. Therefore, through cooling, natural ventilation to improve the indoor thermal environment in summer is to improve people's living environment and living conditions must be considered.

This paper selects the standard layer of a teaching building in Chengdu, Sichuan Province, as the research object. The teaching building is oriented from north to south. The standard level has seven classrooms, one office, two bathrooms, and four stairwells. The west and south sides are the inner corridor is on the north side of the veranda. The classrooms are not equipped with air-conditioning equipment. There is no sunshade device, and the window opening has no fixed size.

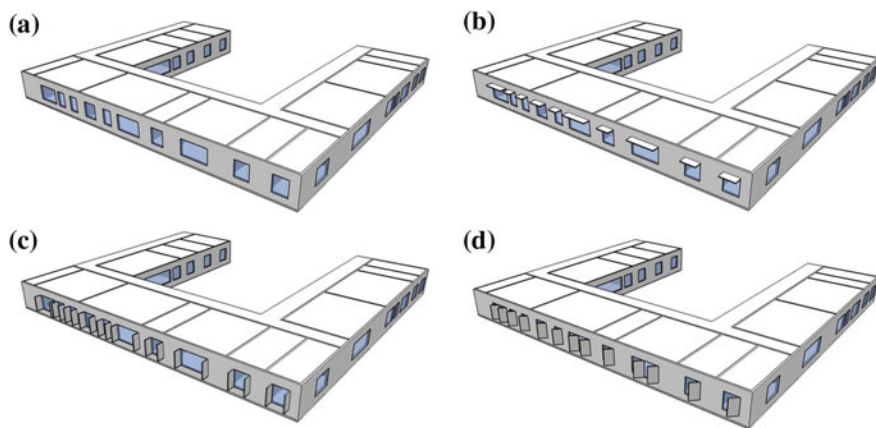
### ***2.2 Methods***

In this paper, the computational fluid dynamics (CFD) method is used to study the indoor thermal environment of school buildings in summer hot and cold winter zone. CFD technology is a kind of numerical simulation technology under the control of flow basic equations. Its general structure consists of pre-processing,

solver, and post-processing. The experimental process is to first model the physical space to the computation space, then mesh to achieve the discrete space of the continuous space, based on the correlation between the variables and the physical domain to establish algebraic equations, and finally, by solving the algebraic equations out of its speed field, temperature field, pressure field, and other data. Currently, mainstream CFD software were Fluent, PHOENICS, STAR-CD, FLOW-3D, etc. Among them, PHOENICS-FLAIR is the UK Cham company for construction and HVAC professional design of the CFD special module, so that these complex flow calculation of the cumbersome mesh generation and boundary conditions set up to greatly reduce, in practical applications are more convenient. In this paper, PHOENICS-FLAIR was used to study the indoor thermal environment of school buildings in summer.

### 2.3 Physical Model and Boundary Condition

In order to reduce the node of this calculation and speed up the calculation convergence, the construction plane is appropriately simplified in this calculation. The effects of different optimization design strategies on building temperature, wind speed, PMV are compared by optimizing horizontal sunshade components, vertical sunshade construction, and air guide plate, and the width of shading member is 900 mm according to the size of common shading structure in hot summer and cold winter areas. The original building model and the model after optimization design are shown in Fig. 1. The number of classrooms on the west side of the teaching building is large. Therefore, the indoor thermal environment in the west-side classroom is selected for research and analysis.



**Fig. 1** a Original building models; b optimization building model of horizontal shading; c optimization building model of vertical shading; d optimization building model of air guide plate

The calculated area size during simulation is 200 m × 200 m × 24 m, and the model scale is 1:1. The region mesh is divided into 106 cells in the X mesh by the free mesh, 106 cells in the Y mesh, and 30 cells in the Z mesh. The PARSOL technique is used to improve the accuracy of the flow field simulation of the fluid or solid boundary obliquely intersecting the Cartesian grid or the polar grid element, avoiding the step shape on the boundary due to the structured grid. When the mathematical model is selected, the standard k-ε model is considered to have low computational cost. In the numerical calculation, the fluctuation is small and the precision is high. It is widely used in numerical simulation of low-speed turbulence. Therefore, the standard k-ε model is adopted in this paper.

In the atmospheric boundary layer, due to the effect of surface friction, the wind speed close to the surface decreases as the height from the ground decreases. Only in places where the ground is more than 300–500 m away, the wind speed is not affected by the surface and can flow freely under the action of the atmospheric gradient. The variation law of the wind speed of the flow surface is expressed as an exponential rate:

$$\frac{U}{U_r} = \left(\frac{Z}{Z_r}\right)^\alpha \quad (1)$$

where  $U_r$  and  $Z_r$  are the reference velocity and height;  $\alpha$  is a power exponent determined by the roughness of the terrain. The reference height  $Z_r$  is generally at a height of 10 m.

Considering the inconsistency of the actual ground roughness, the terrain roughness selected in this study is 0.03. Since the height of 1.5 m is usually the area that people feel on the face, the flow field at a height of 1.5 m from the ground is selected as the inspection point. In this study, the meteorological parameters were selected according to the standard meteorological data of Chengdu. In order to make the calculation meaningful, the most unfavorable conditions were selected for the simulation. Therefore, the meteorological data of the great hottest day on July 22 was selected, the ambient temperature was 31.8 °C, and the wind direction was N-N-E. The center angle is 22.5°, the wind speed is 1.4 m/s, and the humidity is 70%.

### 3 Result and Discussion

#### 3.1 *Effects of Different Optimization Schemes on Indoor Wind Speed*

For the teaching building, the students sitting at the window receive more direct sunlight than the students who are biased inside, resulting in poorer thermal comfort. In order to facilitate the comparison and analysis after the transformation,

this paper selects the point in the Western classroom near the window-edge coordinates (78, 100, 1.5) as the standard point for comparative analysis.

Through the PHOENICS simulation calculation, the indoor wind speed after horizontal sunshade, vertical sunshade, and wind deflector design is shown in Fig. 2. The simulation results show that the original building wind speed is 0.50 m/s. After different renovation design, the indoor wind speed has improved to different degrees. The wind speed after the optimization design of the louver guide wind is the most obvious, reaching 0.91 m/s. According to the actual wind direction, the air guide plate member tilts the 45° setting on the basis of vertical shading to guide the wind direction to speed up the wind speed. The optimized wind speeds of vertical and horizontal shading elements were 0.82 m/s and 0.62 m/s, respectively.

### 3.2 Effects of Different Optimization Schemes on Indoor Temperature

Through the PHOENICS simulation calculation, the simulation results of the indoor temperature after using different optimized designs are shown in Fig. 3. The indoor temperature of the original building is extremely high, reaching 44.27 °C. After various optimization designs, the indoor temperature has been improved to different extents. The temperature reduction after the vertical shading optimization design is

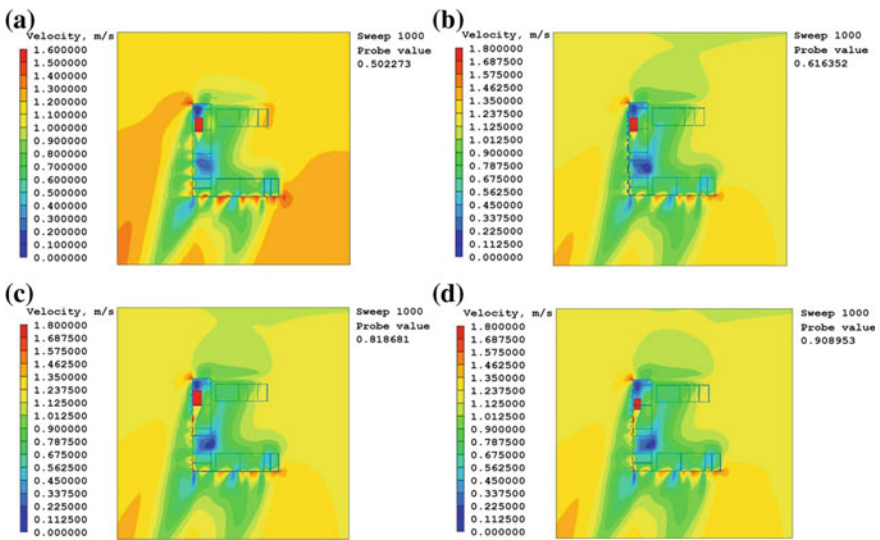
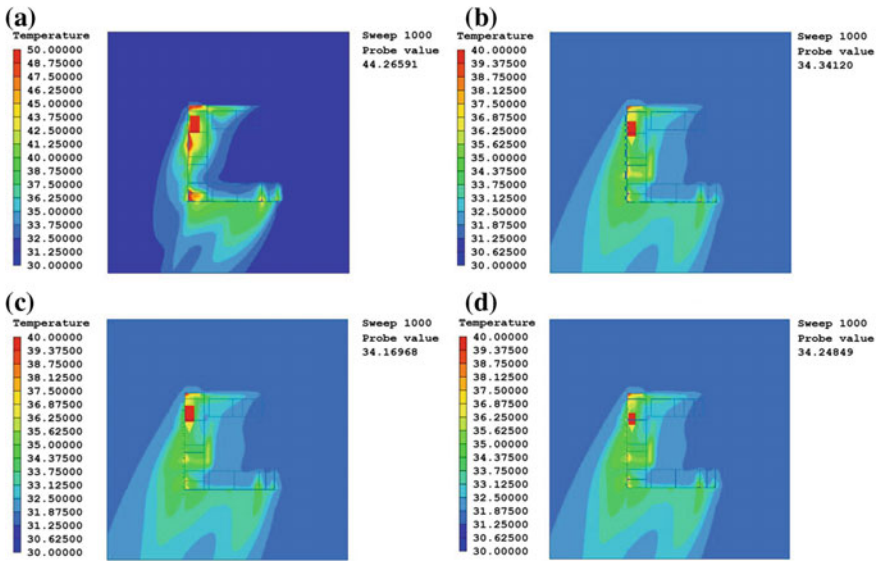


Fig. 2 a Simulation of wind field in original building; b optimization of wind field simulation by horizontal shading; c optimization of wind field simulation by vertical shading; d optimization of wind field simulation of air guide plate



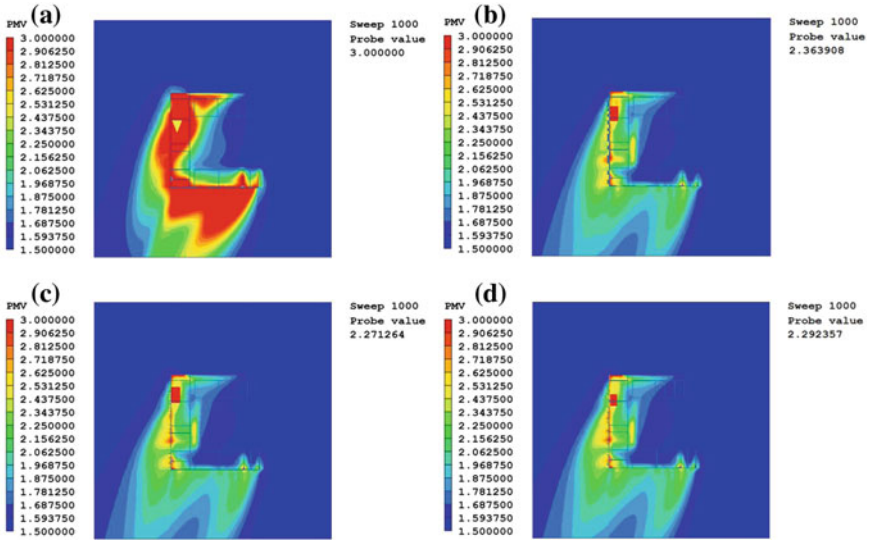
**Fig. 3** a Simulation of temperature field of original building; b optimization of temperature field simulation by horizontal shading; c optimization of temperature field simulation by vertical shading; d optimization of temperature field simulation of air guide plate

most obvious, reaching 34.17 °C. The indoor temperature after optimization using the air guide plate and the horizontal shading component is 34.25 °C and 34.34 °C, respectively.

### 3.3 Effects of Different Optimization Schemes on Indoor PMV Index

The thermal sensation PMV-PPD index was proposed by Danish scientist Fanger in the 1970s and is currently widely used for thermal comfort evaluation. The PMV index is based on the basic equation of human body heat balance and the level of subjective thermal sensation of psychophysiology, taking into account the comprehensive evaluation indicators of many related factors of human thermal comfort. In this paper, the PMV index calculated by PHOENICS software is used to visually evaluate the current indoor thermal environment of school buildings. Before the calculation, the thermal resistance parameters of the simulation model are set: The metabolic rate is set to 1.2 met, and the thermal resistance of the garment is set to 0.6 clo.

The simulation results are shown in Fig. 4. The thermal comfort of the original building is very poor, and the PMV index reaches 3. After different optimization design, the indoor thermal comfort degree has been improved to varying degrees,



**Fig. 4** a Simulation of the PMV value of original building; b optimization of the PMV value simulation by horizontal shading; c optimization of the PMV value by vertical shading; d optimization of the PMV value simulation of air guide plate

among which the PMV index decreased most obviously after the vertical shading optimization design, reaching 2.27. The optimized PMV values of the air guide plate and the horizontal shading member were 2.29 and 2.36, respectively.

### 4 Conclusions

The results of this paper show that the current situation of indoor thermal environment in summer in hot summer and cold winter zone is very poor, the temperature is high and the wind speed is low, and the human body is extremely uncomfortable under natural ventilation. After optimizing with different types of shading facilities, air guide plate, and other energy-saving design strategies, the indoor thermal environment has been improved to varying degrees. Among them, the vertical shading has the most obvious effect on improving the indoor thermal environment. The air guide plate has a significant effect on accelerating the indoor wind speed. However, under the condition that the indoor wind speed is not high, the wind speed has little influence on the PMV, and the temperature becomes a decisive factor affecting the indoor thermal comfort.



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**Ethical standards** The authors declare that the experiments comply with the current laws of the country in which they were performed.

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