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Influence of Outdoor Wind Environment on Thermal Environment Around Rural Houses

JI Chang-fa[1*], ZHANG Huan[1] and FU Ying[1]

[1] College of Energy Science and Engineering, Xi'an University of Science and Technology, Xi'an ,Shaanxi,710054,China

[*]Corresponding author's e-mail: jicf@xust.edu.cn

Abstract. According to statistics, building energy consumption accounts for 33% of the country's total energy consumption, in which rural building energy consumption accounts for 20%, and with the continuous advancement of new rural construction, various policies to benefit the people have been promulgated successively, this proportion will increase year by year.However, at present, the focus of building energy conservation work is concentrated in urban areas. Rural houses lack technical guidance on energy conservation in buildings. The self-built model is basically adopted, which consumes too much energy. Therefore, based on the CFD numerical simulation technology, this paper takes some rural houses in Xi'an as a research object, simulates its outdoor wind environment, combined with the wind environment evaluation standard, the existing problems of rural houses are analyzed, and the improvement scheme is proposed. After the adjustment, the simulation analysis again showed that when the angle between the rural house building and the wind direction in Xi'an is 45 °, the comfort of human living environment is the best, which provides a reference for future energy conservation and consumption reduction in rural areas.

1. Introduction

Improving the rural living environment and building beautiful and livable villages is an important task in implementing the rural revitalization strategy. With the national policy's attention to rural life, the issue of constructing comfortable and energy-efficient rural houses has been paid more attention. As far as the current research status of energy efficiency in rural buildings is concerned, most domestic and foreign scholars focus on the research and analysis of building envelope and indoor thermal environment, while the discussion of outdoor wind environment is concentrated in urban areas, and related research in rural areas is lacking.

Li Jinping used DeST-h software to simulate and analyze the heating energy consumption of typical northwest new rural buildings with different external wall insulation thickness, and determined the best external wall economic insulation thickness[1]. Chen Qiya and others analyzed and compared energy-saving measures in the whole life cycle using the income-to-investment ratio SIR economic benefit evaluation index, and obtained the energy-saving design and renovation measures of rural residential building envelopes in cold areas with the best economic benefits[2]. Zhang Xiaodan used ADINA software to calculate the heat transfer of different forms of walls, and discussed the influence of the heat transfer coefficient of the wall on its temperature. Under the conditions of meeting the specifications, he proposed a method that saves materials and can obtain the best insulation effect. [3]. Ma Chao and others analyzed the building form factor, window-to-wall ratio, thermal performance of the envelope structure, and building energy consumption, and put forward energy-saving and heating strategies suitable for residential buildings in northwest rural areas[4].

However, for rural areas, the natural environment has a much greater impact than the artificial environment, and the formation of a comfortable and livable outdoor wind environment is the guarantee for the comfort of residents' outdoor activities and the small energy consumption indoors. In this context, now this paper takes a rural house in Xi'an as an example for research and analysis.

2. Wind environment evaluation standard

Reasonable and effective evaluation strategies can not only comprehensive description of the simulation results, but also visual simulation results show the pros and cons. However, the theory and practice of wind environment assessment are still in the development stage, and there are many kinds of assessment methods, and there is a great deal of arbitrariness in selecting assessment methods. At present, the Beaufort wind scale (Table 1) drawn up by the British meteorologist Francis Beaufort in 1805 is often used to assess and classify pedestrian height wind comfort standards.

Table 1. Beaufort Class

Wind level	name	Wind speed at 10 m height(m/s)	The situation on the ground
0	Calm	0-0.2	Quiet, smoke straight up
1	Light air	0.3-1.5	The weather vane does not turn
2	Light brooze	1.6-3.3	Wind vane turning
3	Gentle breeze	3.4-5.4	The leaves and twigs are shaking, and the flag is unfolding
4	Moderate breeze	5.5-7.9	Blowing the ground dust and paper, the small branches shake
5	Fresh breeze	8.0-10.7	The leafy tree swayed whole, and the inland water surface was rippled

According to Beaufort's wind-level evaluation standards[5], combined with the relevant regulations on improving the wind environment in residential areas in the "China Ecological Housing Technology Evaluation Manual" and the "Green Building Evaluation Standards" GB/T 50378-2014 revised by the Ministry of Housing and Urban-Rural Development in 2015, it is proposed for rural areas The wind environment evaluation standards for residential areas are as follows:

1 Under typical wind speed and direction conditions in winter:

1) The wind speed in the pedestrian area around the building is less than 5m/s;

2) Except for the first row of buildings facing the wind, the wind pressure difference between the windward side and the leeward side of the building is not more than 5Pa;

2 Under the conditions of typical wind speed and direction in transition season and summer:

1) There is no vortex or windless area in the human activity area of the venue;

3) The wind pressure difference between the indoor and outdoor surfaces of more than 50% of the openable external windows is greater than 0.5Pa;

The wind speed conditions for pedestrian height and comfort shall ensure:

1) The static comfortable wind speed does not exceed 3.1m/s;

2) Comfortable wind speed for walking: no more than 5m/s[6].

3. Case Analysis

3.1. Project overview

After comprehensively considering the architectural layout and spatial form of multiple villages, a representative village in Xi'an was finally selected as the research object. Part of the rural house (figure 1) with a length of 105 meters and a width of 45 meters is taken as the calculation control area.

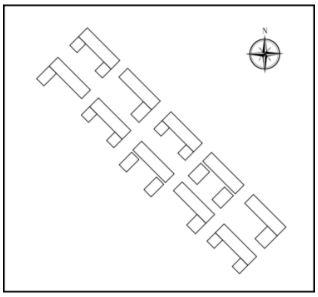

Figure 1. The floor plan of the simulation area

3.2. Climate characteristics
Through field investigation and analysis of local meteorological data, the annual average temperature of this place is 13.2℃, the average maximum temperature is 19.3℃, and the average minimum temperature is 8.1℃. The annual extreme maximum temperature is 41.4℃, the minimum is -20.8℃, and the annual average temperature on the ground is 15.7℃. The dominant wind direction in summer is southwest wind, with an average wind speed of 1.6m/s, and the frequency of the most wind direction is 18%. In winter, the dominant wind direction is northeast wind, with an average wind speed of 1.7m/s and the frequency of the most wind direction is 6%[7].

3.3. Simulation steps

3.3.1. Select simulation software
PHOENICS is a general-purpose software for simulating heat transfer, flow, reaction, and combustion processes. It has the characteristics of good openness and ease of use. Therefore, PHOENICS software was selected for this simulation[8].

3.3.2. Select the mathematical model
The standard $\kappa-\varepsilon$ model is widely used in the numerical simulation of low-speed turbulent flow such as wind flow. It has the characteristics of high calculation accuracy, fast efficiency, good applicability, and low simulation cost. Therefore, the standard $\kappa-\varepsilon$ model is used in this simulation to solve the surrounding wind environment. The governing equations involved mainly include continuity equation, momentum equation and energy equation.

3.3.3. Simplified physical model
On the premise of not affecting the flow field distribution around the building, in order to reduce the number of nodes in the simulation calculation, it is usually necessary to simplify the concave and convex parts of the building. In the actual simulation, this paper does not consider the details of the interior of the building, and ignores the tiny bumps such as doors, windows, decorations, etc., to simplify the building into a regular cube.

3.3.4. Set calculation area
Rural residential areas are mostly located on the fringe of cities, with low houses and open surroundings. There is no shelter around the house, which is greatly affected by the wind in windy weather. In addition, the windward area of the building, the direction of the incoming wind, the volume and spacing of the residences, etc. will all affect the quality of the outdoor wind environment.Therefore, in order to make the simulation results more accurate, avoid the interference of the incoming flow surface from the model and the actual flow field distribution from the outflow surface, after selecting the simulated residence, the set calculation control area must be large enough to ensure the simulation The air flow in the area is sufficient and stable, and a large range of inflow and outflow surfaces are determined. But if the area is too large, it will also increase the calculation cost. According to experience, the calculation control area is taken as part of the rural house (X=105m,

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Y=45m, Z=7.5m) and the surrounding large area (5X×6Y×12Z). The calculation area is shown in figure 2.

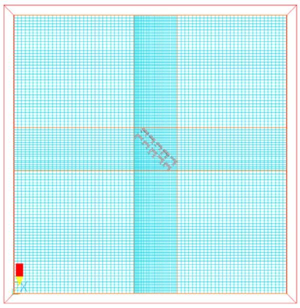

Figure 2. Calculation area

3.3.5. Determine boundary conditions

(1) Boundary conditions of incoming flow surface

The wind speed is evenly distributed in the direction of the building's incoming flow, and the incoming wind speed on the plane of different heights increases according to a gradient along the height of the building. In the simulation analysis, the wind speed is set according to the atmospheric boundary layer theory. The wind speed gradient of different terrains is different, and the wind speed of different heights is different. The calculation formula of wind speed and height is as follows:

$$V_h = V_0\left(\frac{h}{h_0}\right)^n$$

The formula:

Vh—wind speed at height h, m/s;

V0—The reference height is the wind speed at h0, m/s;

n-index, according to "Building Structure Load Code" GB50009-2001, the index is 0.16 for fields, villages, jungles, hills and towns and suburbs where houses are relatively sparse.

(2) Outflow surface boundary conditions

The air flow has been fully developed when it reaches the outlet surface, so the pressure at the outlet is set to atmospheric pressure.

(3) Boundary conditions of side face and upper surface

Since the range of the control area taken is large enough, the influence of the simulation object on the airflow on the side and upper air surface can be ignored, so it is set as a free sliding surface.

(4) Ground and building boundary conditions

The standard $\kappa-\varepsilon$ model is only applicable to the completely turbulent area at a certain distance from the wall, and the viscous effect of laminar flow near the wall is strengthened, so the model must be modified by the wall function method.

3.4. Simulation analysis

3.4.1. Summer conditions

(1) Velocity distribution cloud diagram and velocity distribution vector diagram

The summer in Xi'an is hot and the annual maximum temperature can reach 41.4℃. It is necessary to strengthen ventilation to improve the outdoor environment comfort. The 1.5m height is often the area felt by the human face, so the flow field 1.5m above the ground is selected as the investigation point. Through simulation calculation, the velocity distribution cloud diagram and velocity distribution vector diagram at 1.5m under summer conditions are obtained.

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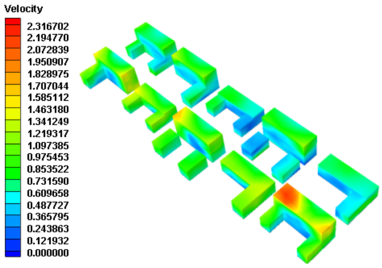

Figure 3.Cloud diagram of velocity distribution at 1.5m in summer

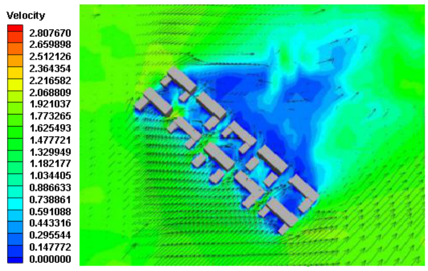

Figure 4.Vector diagram of velocity distribution at 1.5m in summer

From the simulation results shown in figure 3, it can be seen that the external wind speed of the house in summer is between 0.09m/s-2.3m/s, the wind field in the front row of rural houses is evenly distributed, the wind speed is higher, and the wind speed in the rear row of rural houses is relatively It is low, and the personnel activity area is comfortable. From the simulation results shown in figure 4, it can be seen that the front row of rural houses hinder air flow, and the incoming flow is blocked and deflected in all directions to form deflected airflow. The rear row of rural houses are basically in the wind shadow area, and the wind speed is less than lm/s, which affects pollution. The dissipated material may have adverse effects on the health of residents.

(2) Surface pressure distribution diagram of rural house

The most basic power of natural ventilation is wind pressure and heat pressure. Wind pressure ventilation uses the pressure difference between the windward and leeward surfaces of the building to achieve air circulation. The greater the pressure difference, the better the ventilation effect. The use of wind pressure to promote the circulation of indoor air in buildings, improve the environmental quality of indoor air, and achieve natural ventilation and energy saving are currently commonly used building treatment methods[9].

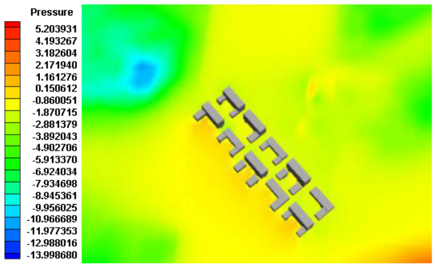

Figure 5.Distribution of surface pressure on rural houses in summer

3.4.2. Winter conditions

(1) Velocity distribution cloud diagram and rural house surface pressure distribution diagram

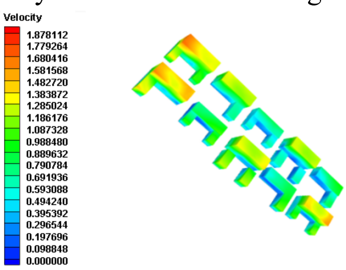

Figure 6.Velocity distribution diagram at 1.5m in winter

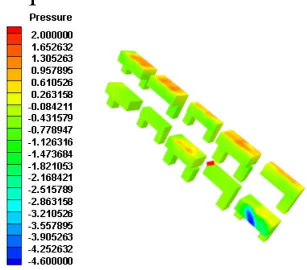

Figure 7. Surface pressure distribution of rural houses in Winter

According to the simulation results shown in figure 6, the external wind speed of the residence in winter is between 0.07m/s-1.8m/s, and the wind speed at the corners is the highest, which does not affect the comfort of personnel activities. The simulation results shown in figure 7 show that, except for the first row of buildings facing the wind, the difference in surface wind pressure between the facing and leeward surfaces of the residence is not more than 5Pa, which meets the relevant regulations in the wind environment assessment standard.

4. Energy-saving improvements

4.1. Energy saving improvement plan

4.1.1. Adjust the wind direction projection angle
The wind direction projection angle is the angle between the wind direction projection line and the wall normal. The smaller the wind projection angle, the better the natural ventilation of the room, but too small a wind projection angle will cause vortexes on the leeward side. According to the available data, as the projection angle increases from 0° to 60°, the indoor wind speed is reduced by 50%, and the depth of the vortex area behind the house is reduced by 2.25H. Therefore, considering the room wind speed, vortex area, and land saving, the wind direction and buildings should have a certain wind direction projection angle, and the projection angle is the most appropriate at 45°[10].

4.1.2. Increase the spacing between buildings
Reasonably arranging the relative positions of the buildings can slow down the changes in wind speed, guide the flow of wind, and improve the corner position and the wind field distribution of the rear buildings. In the case of high local wind speeds, for local areas, the spacing between front, rear, left and right can be appropriately increased to reduce the layout of buildings in weak wind areas.

4.2. Optimization case analysis
To sum up, now adjust the model house orientation so that the wind direction projection angle is 45° and then simulate.

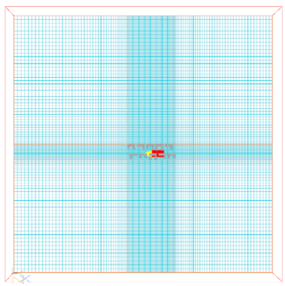

Figure 8. Improved calculation area

4.2.1. Summer conditions
(1) Velocity distribution cloud diagram and velocity distribution vector diagram

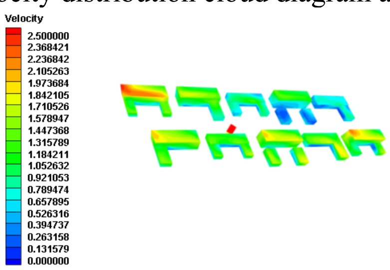

Figure 9.Improved cloud diagram of velocity distribution at 1.5m in summer

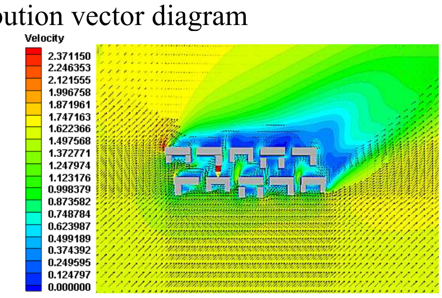

Figure 10. Improved velocity distribution vector diagram at 1.5m in summer

From the simulation results shown in figure 9, it can be seen that after the improvement, only a small part of the outside of the house has wind speeds lower than 1m/s under summer conditions, the wind environment of the rear rural house is improved, and the comfort of the personnel activity area is good. Comparing figure 10 with figure 4, we can see that the area of the wind shadow area is significantly reduced, the wind speed changes slower, the wind speed at the corner is the highest, and the wind field distribution is more even than before.

(2) Surface pressure distribution diagram of rural house

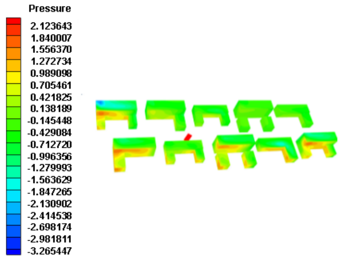

Figure 11.Improved summer rural house surface pressure distribution

According to the simulation results shown in figure 11, after adjusting the orientation of the model house, the negative pressure area is reduced, and the pressure difference between the front and leeward surfaces of the rural house is not more than 5Pa, which conforms to the relevant regulations in the wind environment evaluation standard.

4.2.2. Winter conditions

(1) Velocity distribution cloud diagram and rural house surface pressure distribution diagram

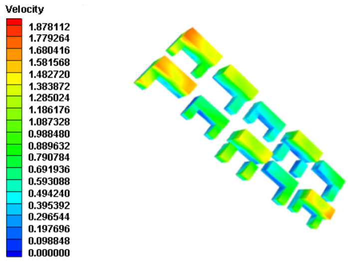

Figure 12.Improved cloud diagram of velocity distribution at 1.5m in winter

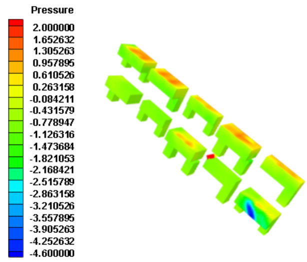

Figure 13. Improved winter rural house surface pressure distribution

According to the simulation results shown in figure 12, after adjusting the orientation of the model house, the external wind speed of the house under winter conditions is between 0.09m/s-1.8m/s, and the average wind speed is 1.1m/s, which does not affect the comfort of personnel activities. According to the simulation results shown in figure 13, after adjusting the orientation of the model house, the leeward side of the house can maintain positive pressure, which is beneficial to the diffusion of pollutants. The wind pressure difference between the windward and leeward surfaces is not more than 5Pa, which conforms to the relevant regulations in the wind environment assessment standard.

5. Conclusions

This paper takes a rural area in Xi'an as the research object, and analyzes the distribution of wind speed and wind pressure on the outside surface of the rural house under winter and summer conditions through CFD technology simulation, and the following two points are obtained:

(1) In summer, due to the front row of rural houses blocking the air flow, the incoming flow is blocked and deflected in all directions around. The rear row of rural houses is in the wind shadow area, the wind speed is less than lm/s, and the negative pressure is formed on the leeward side, which affects Dissipation of pollutants and is bad for the health of residents.

(2) In winter, the average external wind velocity of the residence is about 1.3m/s, which does not affect the comfort of personnel activities, and the pressure difference between the front and leeward surfaces is not more than 5Pa, which meets the relevant regulations in the wind environment evaluation standard.

In order to solve the above problems, an optimization plan was proposed and the simulation was performed again to draw the following conclusions:

(1) Considering the factors such as room wind speed, vortex area and land saving, it is proposed to control the projection Angle of wind direction between 30 and 60 degrees (45 degrees is the best).

(2) Increase the distance between the front and rear houses to prevent the rear houses from being in the wake area of the front houses.

(3) After the improvement, the overall natural ventilation environment of the residential community has been significantly improved. Although there will be a small area of wind shadow, the wind field in the residential area is evenly distributed. The average outdoor wind speed is lower than 5m/s, and the wind environment in the area is more comfortable. The pressure difference between the front and the leeward side of the farm house is not more than 5Pa, and the leeward side can basically maintain a positive pressure, which is conducive to the diffusion of pollutants and meets the relevant regulations in the wind environmental assessment standards.

Acknowledgments
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