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Impact of Rural Courtyard Layout Factors on its Wind Environment Comfort: A Case Study of Beixindian Village

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Abstract The wind environment serves as an important indicator of the comfort level of the human settlement environment. A favorable wind environment in courtyards can offer residents a better living and activity environment. Based on the *Climatic Suitability Evaluating on Human Settlement*, this study employs Computational Fluid Dynamics (CFD) simulation analysis to evaluate the wind environment comfort in rural courtyards, and elucidates the interactions between various factors influencing the courtyard wind environment and the courtyard wind environment. It is anticipated that the findings of this study will serve as a valuable reference for the renovation and new construction of rural houses, with a focus on optimizing the wind environment.

Keywords Rural courtyard, Wind environment, CFD simulation, Working condition
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With the proposal of China's rural revitalization strategy and the enhancement of the rural human settlement environment, the Beijing Municipal Party Committee and Municipal Government place significant emphasis on and actively advocate for building a beautiful countryside. They have proposed a comprehensive initiative aimed at improving rural infrastructure and public service facilities, reinforcing the integrated management of the rural environment, and enhancing the living and production conditions of residents. The objective is to establish beautiful villages and harmonious homes that are characterized by green and low-carbon practices, ecologically sustainable environments, healthy and comfortable lifestyles, and a culture of simplicity and harmony. The rural courtyard serves as a significant space for traditional rural life, providing an advantageous outdoor wind environment that facilitates residential activities, agricultural production, and the storage of goods.

Research on the wind environment of rural courtyards typically integrates field measurements with computational numerical simulations to evaluate the wind environment within these spaces. For instance, Wang et al.[1] examined the influence of courtyard layout on the winter wind environment of a traditional coastal village in Quanzhou through numerical simulations. This study primarily concentrated on the effects of courtyard area, aspect ratio, and orientation on the wind environment within the courtyards. Sun et al.[2] conducted a computer numerical simulation to model the wind environment under various layout configurations in courtyards during winter in the cold region of Northeast China, and subsequently analyzed the wind environment within the courtyards from multiple perspectives. Dong[3] selected a specific village in Northeast China as the focus of the research, and examined the winter wind environment across six distinct courtyard types utilizing both field measurements and numerical simulations. Based on the findings, differentiated optimization strategies were proposed for each courtyard type. Li et al.[4] conducted simulations of the wind environment within courtyards of varying types and influencing factors in a village setting. Their findings indicate that the wind environment within these courtyards can be enhanced through the implementation of different organizational forms, thereby improving the overall comfort of the human environment.

These findings represent a significant contribution to the investigation of factors that influence the wind environment in courtyards. However, several limitations persist. Firstly, the majority of studies have focused on a single season regarding the wind environment of rural courtyards, while neglecting the impact of multiple seasons in collectively regulating the wind environment of these spaces. Secondly, while the wind environment is evaluated using Computational Fluid Dynamics (CFD) simulations, the majority of studies tend to analyze the overall wind conditions based on the observation of simulation results. There is a relative scarcity of research that further examines these simulation results through the application of correlation statistics.

1 Research basis and methods

1.1 Research objects

Beixindian Village is situated in the southeastern region of Beijing, within the northern section of the North China Plain, characterized by a typical temperate continental monsoon climate. The village exhibits a well-organized layout, featuring compact and regular streets and alleys, and is classified as a group style village. The streets and alleys are arranged in a dendritic pattern, with a clearly defined structure for the main streets and road networks. The housing courtyards predominantly consist of linear-shaped and L-shaped courtyards (Fig.1).

1.2 Meteorological data

In this study, the Weather Tool software was employed to extract meteorological data from the Chinese Standard Weather Data (CSWD). This data primarily included average temperature, wind direction, and wind speed for the three seasons: spring, summer, and autumn. The extracted meteorological data served as the simulation data in the subsequent phases of the research (Fig.2).

The data statistics indicated that the average temperature in Beijing was 25.5 °C in summer, 13.7 °C in spring, and 12.9 °C in autumn. Consequently, the average temperature across these three seasons, which was 17.4 °C, was selected as the simulated temperature setting.

Additionally, two wind directions, northeast and southwest, were chosen as the simulated meteorological parameters concerning wind direction and wind speed. Based on multi-month wind speed statistics, the outdoor wind speed for the northeast direction was determined to be 4.25 m/s, while the outdoor wind speed for the southwest direction was recorded at 4.19 m/s.

1.3 Evaluation criterion for wind environment

This paper employed the proportion of the wind speed comfort zone as the evaluative

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criterion for assessing the wind environment in rural courtyards, based on a thorough investigation and analysis of pertinent literature. Wind speed serves as the most direct indicator of pedestrian comfort levels. According to the national standard *Climatic Suitability Evaluating on Human Settlement* (GB/T 27963–2011)[5], the assessment of climate comfort is conducted differently for the two halves of the year. Specifically, the winter half-year is evaluated using the wind efficiency index, while the summer half-year is assessed based on the temperature and humidity index. In the context of summer assessments, if the average wind speed exceeds 3 m/s, the wind efficiency index should be employed for evaluation purposes. An analysis of the local meteorological data pertaining to wind speeds in Beijing during the spring, summer, and autumn seasons revealed that the average wind speed consistently surpassed 3 m/s. Consequently, the wind efficiency index was utilized in the assessment. The individuals' perceptions of climate comfort across various environments are presented in Table 1. The wind efficiency index is computed using the following formula:

$$K=-(10\sqrt{V}+10.45-V)(33-T)+8.55S$$

where K represents the wind efficiency index, expressed as an integer; T denotes the average temperature over a specified evaluation period, measured in °C; V indicates the average wind speed during the same evaluation period, quantified in m/s; and S refers to the average number of sunshine hours within the evaluation period, recorded in h/d.

According to the aforementioned formula and the research conducted on the meteorological data of Beijing, the average temperature (T) was determined to be 17.4 °C, the average wind speed (V) was established at 4.2 m/s, and the average sunshine duration (S) was recorded as 8.6 h/d. Upon calculating the wind speed (V) in relation to the comfort zone specified, it was observed that the value of K fell within the comfort zone range of −299 to −100 when the wind speed was between 0.004 and 2.65 m/s. Wind speeds below 0.5 m/s are considered unfavorable for human heat dissipation and pollutant diffusion. Consequently, a wind speed comfort zone defined by the range of 0.50–2.65 m/s was established for this study, serving as the evaluation criteria for subsequent simulation results.

1.4 Research methods

Through the application of numerical simulation methods and comparative study techniques, PHOENICS was selected as the numerical simulation software for analyzing wind environments. As a prominent fluid dynamics software, PHOENICS is characterized by its flexible modeling capabilities, user-friendly interface, and high computational efficiency and accuracy. It has been extensively utilized across various research domains for an extended period.

2 Establishment and simulation verification of courtyard models

2.1 Working condition setting of models

The residential structures within this village predominantly consist of single-story courtyards. The main houses are oriented towards the north and south, while the wing rooms are aligned east and west, serving primarily as storage spaces for various items and grains. The architectural design of the roofs predominantly features the traditional Chinese gabled style. According to research on the enclosure form of local residences, courtyards can be categorized into two distinct types: linear-shaped courtyards and L-shaped courtyards. The linear-shaped courtyard is primarily enclosed by the main house and the courtyard wall, whereas the L-shaped courtyard is predominantly enclosed by the main house, the west wing, and the courtyard wall. Initially, two typical models of courtyard configurations were developed. Subsequent alterations to the variables influencing the wind environment in various courtyards were implemented based on these typical models. Each dimension of the typical models served as a reference point, and the two fundamental models are illustrated in Fig.3.

Following the extraction of the typical models for the aforementioned two courtyards, the working conditions of several models were established based on four factors influencing the wind environment within the courtyard: the aspect ratio of the courtyard, the height of the courtyard walls, the location of the courtyard gate, and the orientation of the courtyard. These factors are detailed in Tables 2–5.

2.2 Field wind environment simulation validation

For the two types of courtyards previously discussed, a typical courtyard was chosen for the purpose of wind environment simulation and validation. The height of the measurement equipment was established at 1.5 m, ensuring that the wind blade of the anemometer was oriented towards the prevailing wind direction of the day, as illustrated in Fig.4. The arrangement of the measurement points was classified into two categories based on their spatial location within the courtyard. The first category consisted of four measurement points, designated as A1, A2, A3, and A4, which were situated at the four relatively distant corners of the courtyard. The second category comprised the midpoints, labeled B1, B2, B3, B4, and B5, located along the lines connecting the four corner measurement points. The second category of measurement point B5 was shifted downward due to the wing rooms in the L-shaped courtyard. The data collection process employed a method of recording average values. For the aforementioned measurement points, data was recorded at 15 s intervals, with each point being monitored for 5 min. Following the measurement of one point, the procedure was promptly proceeding to the subsequent point for measurement. Ultimately, the average of the 10 recorded measurements for each point was calculated.

The statistical analysis of the average values of the measurement results was fitted with the wind speed data obtained from the corresponding points in the computer numerical simulation (Table 6). The presence of a limited number of green plants and debris in the courtyard influenced the wind speed measurements. Consequently, the wind speed at certain points exhibited some bias. However, the majority of the points demonstrated a satisfactory fit, and the overall error remained within acceptable limits.

3 Simulation results and analysis of wind environment in rural courtyards

Initially, the wind speed maps of two typical courtyards were analyzed. Subsequently, the proportions of the comfort zone corresponding to two wind directions and two heights were quantified. Finally, regression analysis was conducted on the quantified values to examine the influence of each variable parameter on the wind environment, while simultaneously identifying the relatively optimal parameters for courtyard comfort.

3.1 Aspect ratio of the courtyard

3.1.1 Aspect ratio of the linear-shaped courtyard. As illustrated in Fig.5, the proportion of the average wind speed comfort zone in the linear-shaped courtyard increased with the aspect ratio of the courtyard. A regression analysis conducted on the aforementioned data using SPSS software (Fig.6) revealed that the coefficient of determination (R^2) for the quadratic regression curve was 0.974, with a significance P-value of 0.026, less than the threshold of 0.05. The aforementioned results indicated that the quadratic curve was a suitable fit, and that the aspect ratio of the linear-shaped courtyard exhibited a significant correlation with the proportion of the wind speed comfort zone. According to the statistical data obtained from SPSS, the equation of the curve can be expressed as $y=-18.625x^2+62.265x+28.738$. In this equation, y denotes the dependent variable, which represents the proportion of the wind speed comfort zone, while x signifies the independent variable, representing various aspect ratios of the linear-shaped courtyard. Furthermore, the regression analysis indicated a positive correlation between the average proportion of the wind speed comfort zone and the aspect ratio of the linear-shaped courtyard.

3.1.2 Aspect ratio of the L-shaped courtyard. As illustrated in Fig.7, the proportion of wind speed comfort zones in the L-shaped courtyard decreased with an increase in the

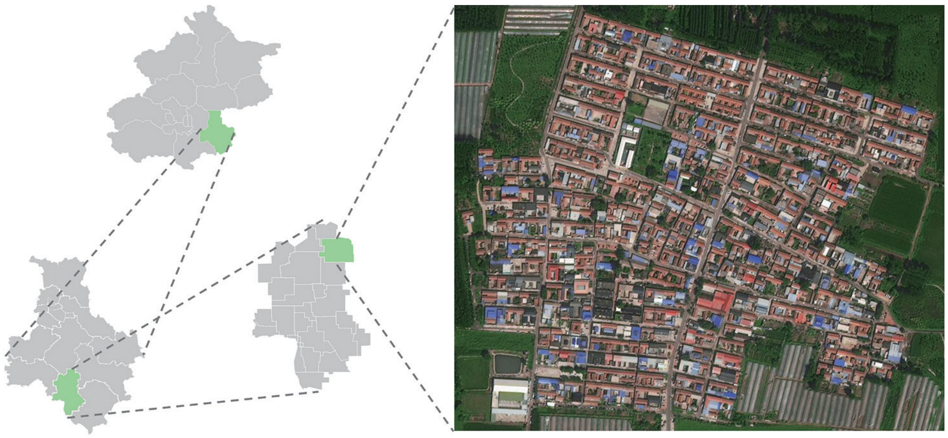
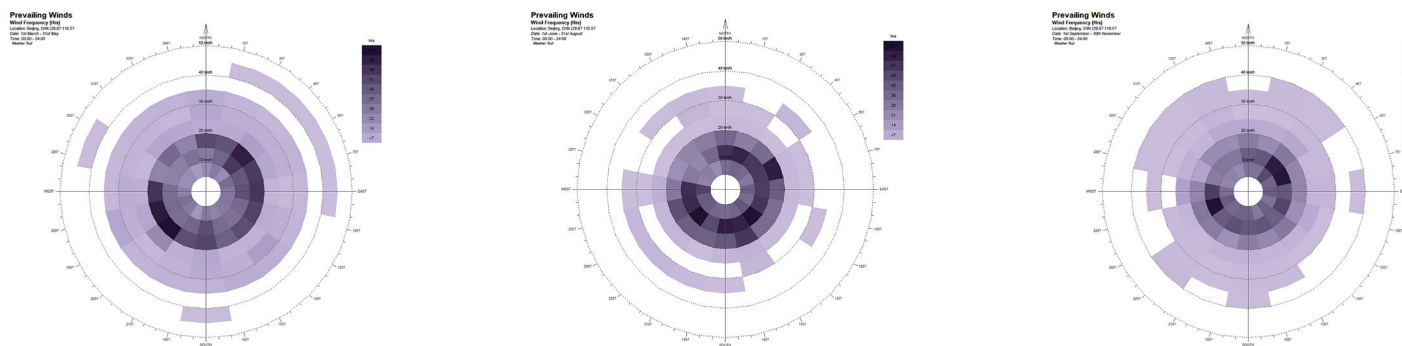


Fig.1 Location of Beixindian Village



Wind frequency of spring   Wind frequency of summer   Wind frequency of autumn

Fig.2 Wind frequency of spring, summer and autumn in Beijing area

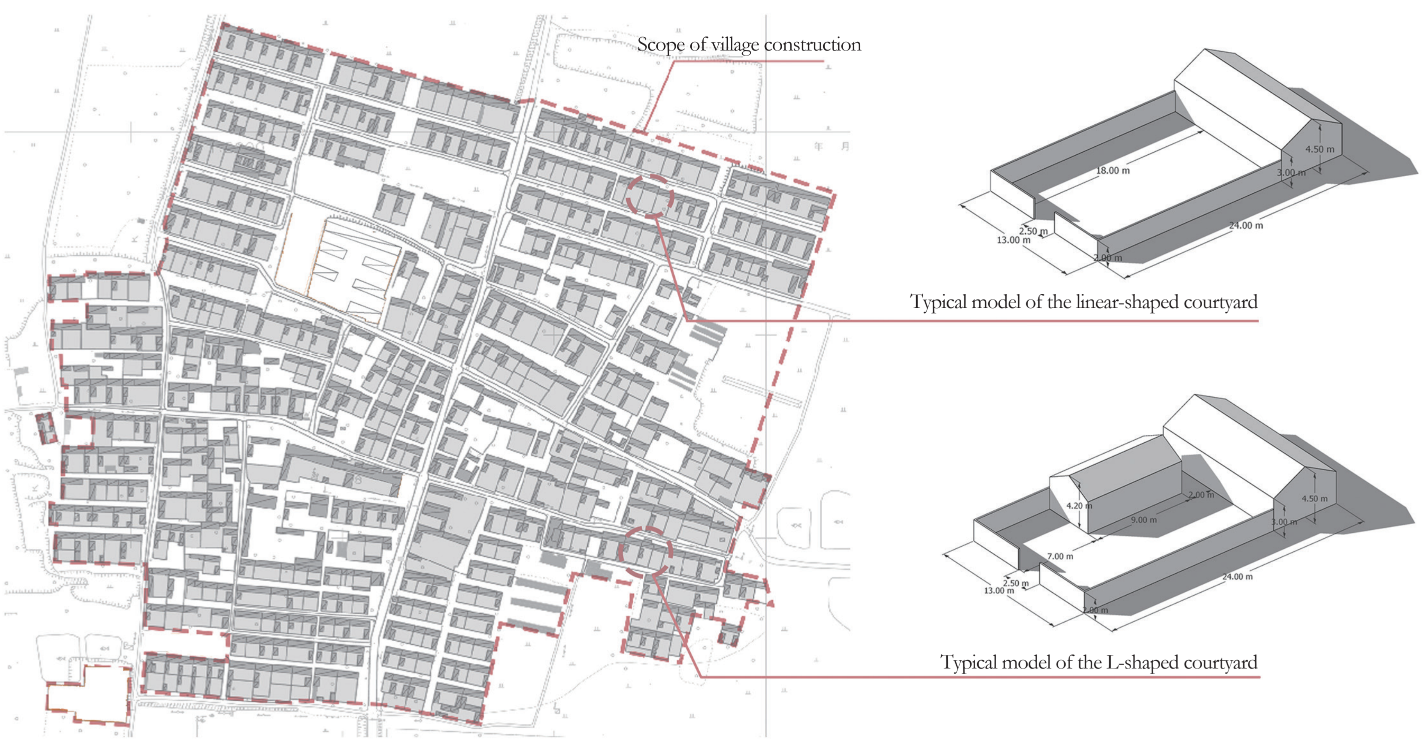


Fig.3 Typical model

aspect ratio of the courtyard. The regression analysis conducted on the average proportion of the wind speed comfort zone in relation to the aspect ratio of L-shaped courtyards (Fig.8) revealed that the coefficient of determination (R^2) for the quadratic regression curve was 0.981. Additionally, the P-value was found to be 0.019, less than the significance threshold of 0.05. This finding suggested that the quadratic curve provided a good fit, indicating a significant correlation between the aspect ratio of the L-shaped courtyard and the proportion of the wind speed comfort zone. The equation of the curve can be expressed as $y=5.679x^2-19.949x+92.009$, where y denotes the dependent variable, which represents the proportion of the wind speed comfort zone, and x signifies the independent variable, which corresponds to the

Table 1 Relationship between wind speed and human comfort under different wind force levels

Level	Degree of sensation	Temperature and humidity index	Wind efficiency index	Description of the feelings of healthy people
1	Freezing	<14.0	<−400	Very cold and uncomfortable
2	Cold	14.0–16.9	−400– −300	Cold and more uncomfortable
3	Comfortable	17.0–25.4	−299– −100	Comfortable
4	Hot	25.5–27.5	−90– −10	Hot and more uncomfortable
5	Muggy	>27.5	>−10	Sweltering and uncomfortable

Table 2 Working conditions of courtyard aspect ratio model

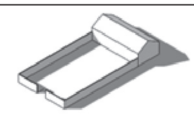
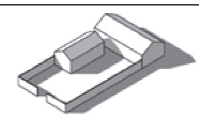
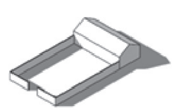
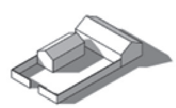
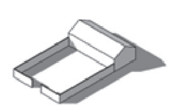
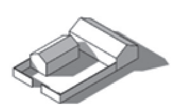
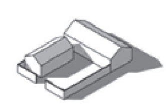
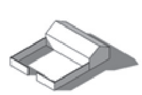
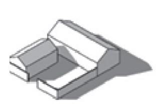
Aspect ratio of the courtyard	Linear-shaped courtyard	L-shaped courtyard
1∶1.6		
1∶1.4		
1∶1.2		
1∶1.0		
1∶0.8		

Table 3 Working conditions of courtyard wall height model

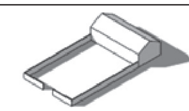
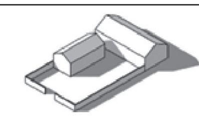
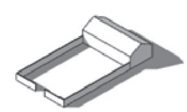
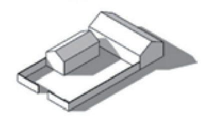
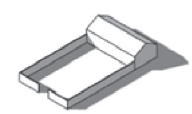
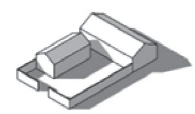
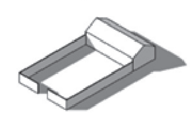
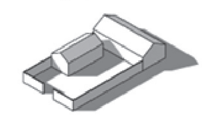
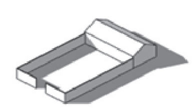
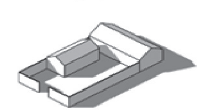
Height of the courtyard wall//m	Linear-shaped courtyard	L-shaped courtyard
1.4		
1.7		
2.0		
2.3		
2.6		

Table 4 Working condition of courtyard gate location model

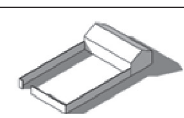
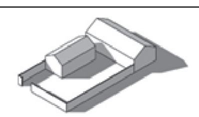
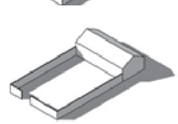
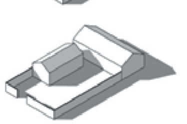
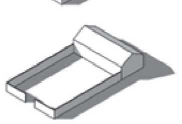
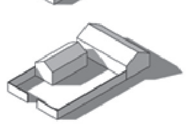
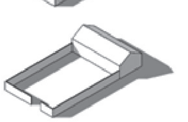
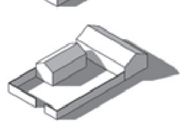
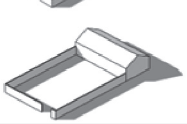
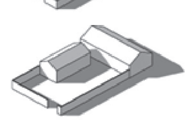
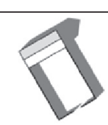
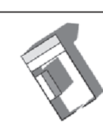
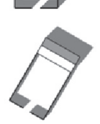
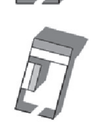
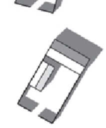
Location of the courtyard gate	Linear-shaped courtyard	L-shaped courtyard
−4		
−2		
0		
2		
4		

Table 5 Working conditions of courtyard orientation model

Orientation of the courtyard	Linear-shaped courtyard	L-shaped courtyard
−30°		
−15°		
0°		
15°		
30°		

various aspect ratios of the L-shaped courtyard. Furthermore, the regression analysis indicated a negative correlation between the average proportion of the wind speed comfort zone and the aspect ratio of the L-shaped courtyard.

3.2 Wall height of the courtyard

3.2.1 Wall height of the linear-shaped courtyard. The data presented in Fig.9 indicated that the proportion of the wind speed comfort zone in the linear-shaped courtyard initially increased and subsequently decreased as the height of the courtyard wall increased. The peak value was observed at a wall height of 2.3 m. The regression analysis conducted on the average proportion of the wind speed comfort zone across various wall heights in the linear-shaped courtyard (Fig.10) indicated that the cubic regression model provided a superior fit compared to both bilinear and linear regression models. This conclusion was supported by a coefficient of determination (R^2) of 0.980 and a significance P-value of 0.020, below the threshold of 0.05. This finding suggested that the three curves exhibited a good fit, and that the height of the courtyard wall in the linear-shaped courtyard was significantly correlated with the proportion of the wind speed comfort zone. According to the analysis, the equation of the curve can be expressed as $y=-1.946x^3+30.098x+34.516$, where y denotes the dependent variable, representing the proportion of the wind speed comfort zone, and x signifies the independent variable, which corresponds to the varying heights of the courtyard wall in the linear-shaped courtyard. Regression analysis indicated that the average proportion of the wind speed comfort zone reached its maximum at a height of 2.3 m in the linear-shaped courtyard. Furthermore, a positive correlation was observed between the two variables when the height ranged from 1.4 to 2.3 m, while a negative correlation was noted beyond this height.

3.2.2 Wall height of the L-shaped courtyard. As illustrated in Fig.11, the proportion of the wind speed comfort zone in the L-shaped courtyard increased with the height of the courtyard wall. A regression analysis conducted on the average proportion of the wind speed comfort zone at varying wall heights in the L-shaped courtyard (Fig.12) indicated that the linear regression model provided a superior fit compared to both the quadratic and cubic models. This was evidenced

Fig.4 Realistic view and actual measurement of the courtyard

Table 6 Comparison of actual measurement results and wind speed fit

<table>
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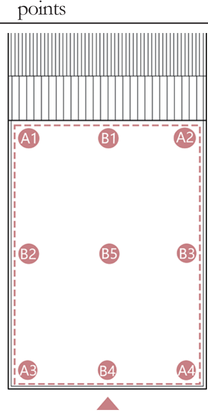
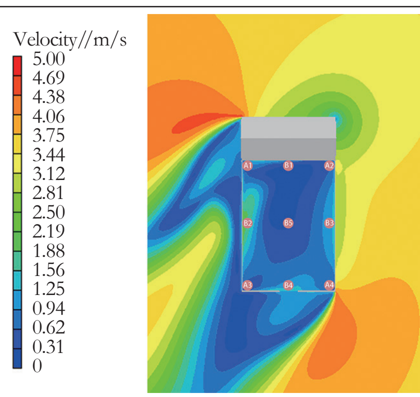
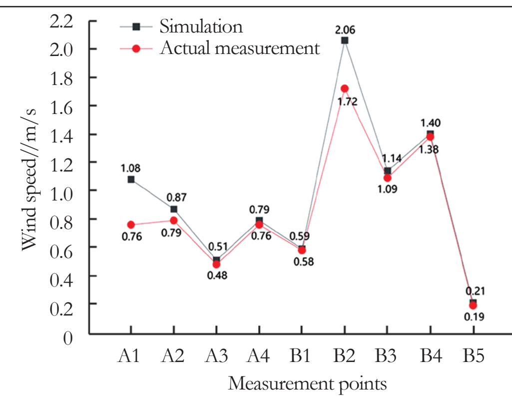
<tr><td>Linear-shaped courtyard</td><td>
</td><td>
</td><td>
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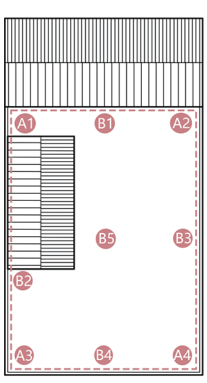
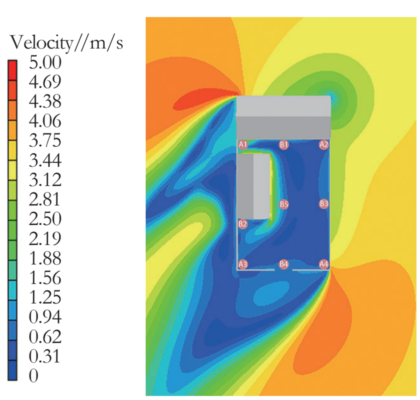
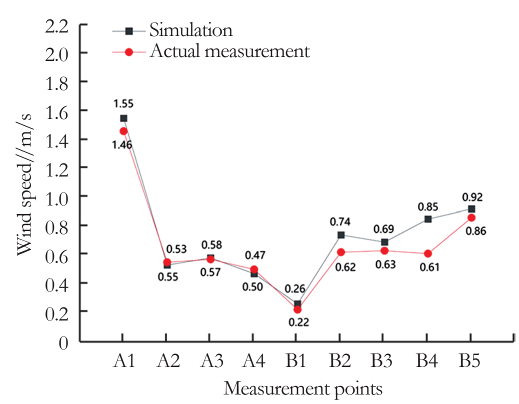
<tr><td>L-shaped courtyard</td><td>
</td><td>
</td><td>
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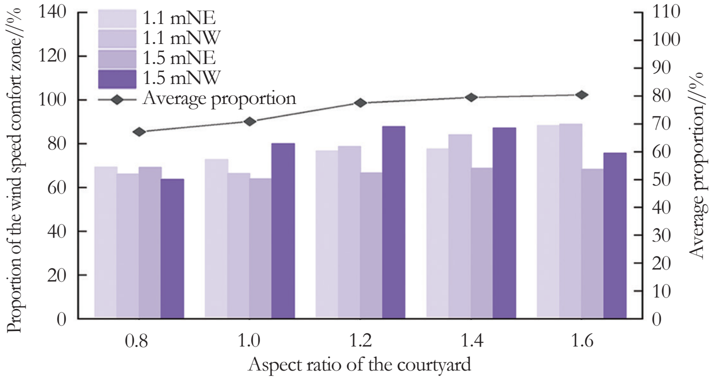

Fig.5 Proportion of the wind speed comfort zone across various aspect ratios

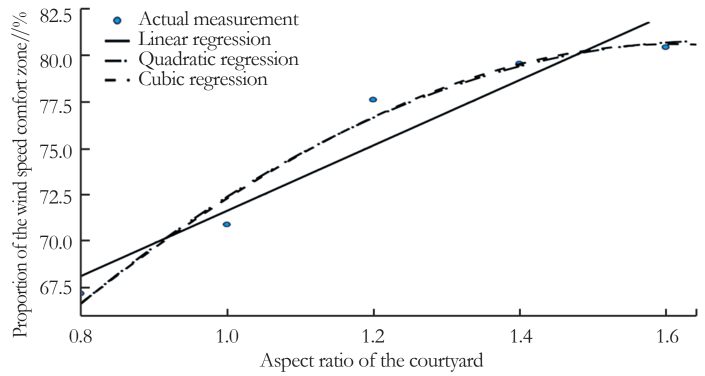

Fig.6 Regression analysis of average proportion and courtyard aspect ratio

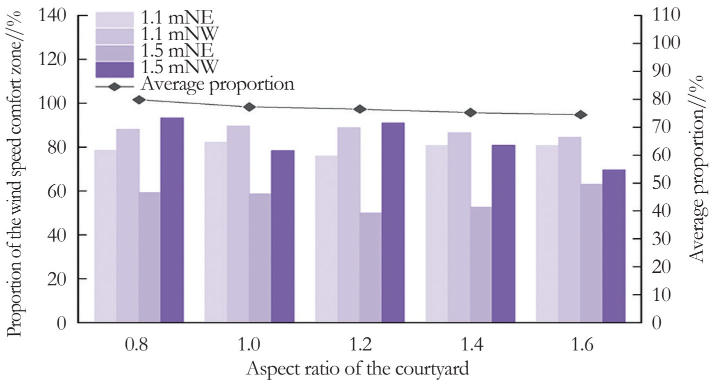

Fig.7 Proportion of the wind speed comfort zone across various aspect ratios

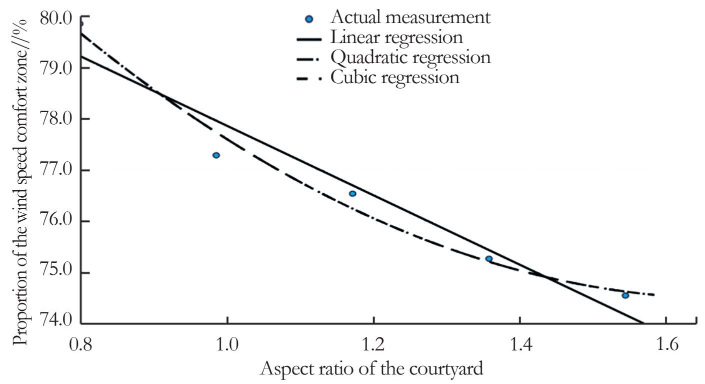

Fig.8 Regression analysis of average proportion and courtyard aspect ratio

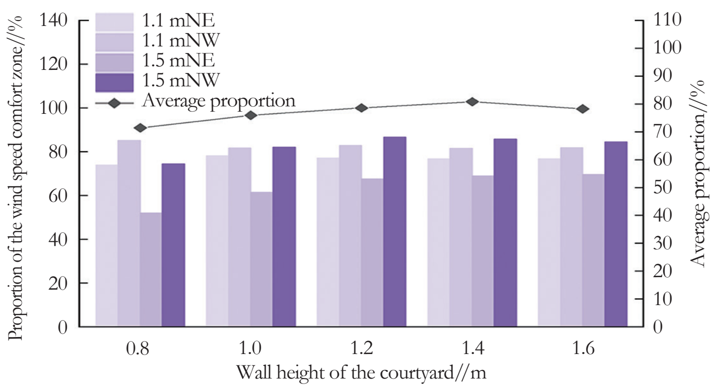

Fig.9 Proportion of the wind speed comfort zone across various wall heights

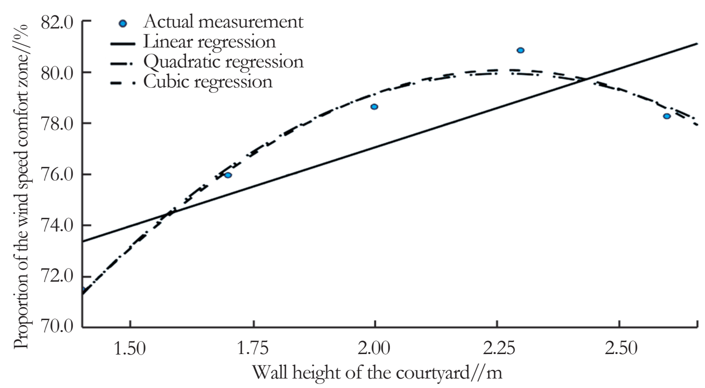

Fig.10 Regression analysis of average proportion and courtyard wall height

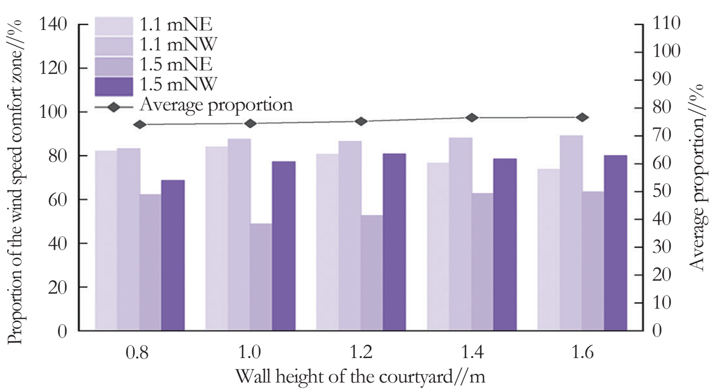

Fig.11 Proportion of the wind speed comfort zone across various wall heights

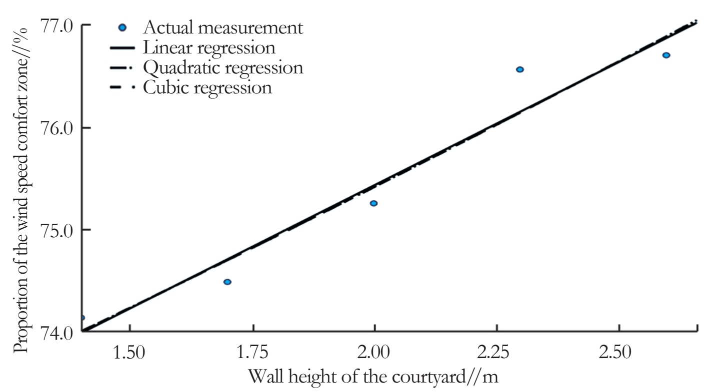

Fig.12 Regression analysis of average proportion and courtyard wall height

by a coefficient of determination (R^2) of 0.945 and a statistically significant P-value of 0.006, less than the conventional threshold of 0.05. This finding suggested that the linear regression model was appropriately fitted, demonstrating a significant correlation between the height of the courtyard wall in the L-shaped courtyard and the proportion of the wind speed comfort zone. According to the analysis, the equation of the curve can be expressed as y=2.407x+70.621, where y denotes the dependent variable representing the proportion of the wind speed comfort zone, and x signifies the independent variable corresponding to the varying heights of the courtyard wall in the L-shaped courtyard. The regression analysis indicated a positive correlation between the average proportion of the wind speed comfort zone and the height of the courtyard wall.

3.3 Location of the courtyard gate

3.3.1 Location of the courtyard gate of the linear-shaped courtyard. As illustrated in Fig.13, there was no discernible trend in the proportion of the wind speed comfort zone in the linear-shaped courtyard as the location of the gate was altered. Notably, the highest proportion of the wind speed comfort zone was observed at a distance of 2 m west of the gate. The regression analysis of the average proportion of the wind speed comfort zone at various gate locations in the linear-shaped courtyard (Fig.14) indicated that the cubic regression model provided a superior fit compared to both the quadratic and linear regression models. This conclusion was supported by a coefficient of determination (R^2) equal to 1 and a significance P-value of 0.011, below the threshold of 0.05. This finding suggested that the linear regression model was appropriately fitted, and that the location of the gate in the linear-shaped courtyard exhibited a significant correlation with the proportion of the wind speed comfort zone. The equation of the curve can be expressed as $y=0.147x^3-0.1x^2-1.905x+78.510$, where y denotes the dependent variable, which represents the proportion of the wind speed comfort zone, and x signifies the independent variable, indicating the various gate locations within the linear-shaped courtyard. The regression analysis revealed that the average proportion of the wind speed comfort zone was maximized at a position approximately 2 m west of the courtyard gate.

3.3.2 Location of the courtyard gate of the L-shaped courtyard. As illustrated in Fig.15, the proportion of the wind speed comfort zone in the L-shaped courtyard exhibited an initial increase followed by a subsequent decrease from the west to the east, contingent upon the location of the gate. Notably, the proportion of the comfort zone reached its peak when the gate was situated at the center of the courtyard. The regression analysis conducted on the average proportion of the wind speed comfort zone across various gate locations in the L-shaped courtyard (Fig.16) revealed that the significance P-values for the linear, quadratic, and cubic regression models were 0.213, 0.051, and 0.223, respectively. All of these values exceeded the threshold of 0.05, indicating a lack of significant correlation between this influencing factor and the proportion of the wind speed comfort zone. Consequently, it is not feasible to predict the proportion of the wind speed comfort zone based on the gate location in the L-shaped courtyard.

3.4 Orientation of the courtyard

3.4.1 Orientation of the linear-shaped courtyard. As illustrated in Fig.17, there was no discernible correlation between the overall proportion of the wind speed comfort zone and the angle of courtyard orientation. Notably, the proportion of the wind speed comfort zone reached its peak when the courtyard was oriented at an angle of 30° to the east. The regression analysis conducted on the average proportion of the wind speed comfort zone across various orientations of the linear-shaped courtyard (Fig.18) revealed that the P-values for the linear, quadratic, and cubic regression models were 0.171, 0.425, and 0.615, respectively. All of these values exceeded the threshold of 0.05, indicating a lack of significant correlation between the orientation of the courtyard and the proportion of the wind speed comfort zone. Consequently, it is not feasible to predict the proportion of the wind speed comfort zone based on variations in the orientation of the linear-shaped courtyard.

3.4.2 Orientation of the L-shaped courtyard. As illustrated in Fig.19, no discernible pattern emerged regarding the orientation of the L-shaped courtyard in relation to the proportion of the wind speed comfort zone. Optimization could only be measured when the courtyard was situated at an angle of 30° to the east. The regression analysis conducted on the average proportion of the wind speed comfort zone across various orientations of the L-shaped courtyard (Fig.20) revealed that the P-values for the linear, quadratic, and cubic regression models were 0.075, 0.070, and 0.324, respectively. All of these values exceeded the threshold of 0.05, indicating a lack of significant correlation between the orientation of the courtyard and the proportion of the wind speed comfort zone. Consequently, it is not feasible to predict the proportion of the wind speed comfort zone based on variations in the orientation of the L-shaped courtyard.

4 Conclusions

This study investigated the wind environment of rural courtyards, focusing on the existing courtyard types within a specific village. Four factors influencing two typical courtyard models were examined: the aspect ratio of the courtyard, the height of the courtyard wall, the location of the courtyard gate, and the orientation of the courtyard. Various parameter settings were applied, and regression analyses were conducted to assess the proportion of the wind speed comfort zone, as well as the correlation between the wind environment and the four influencing factors. The results of this analysis are presented below.

(1) In the case of a linear-shaped courtyard, when the aspect ratio of the courtyard is 1.6, the height of the courtyard wall is 2.3 m, the courtyard gate is situated 2 m to the west, and the orientation of the courtyard is at an angle of 30° to the east, the proportion of the wind speed comfort zone among the influencing factors of the courtyard layout is maximized. In the context of the L-shaped courtyard, the wind speed comfort zone for each influencing factor of the courtyard layout achieves its maximum proportion when the aspect ratio of the courtyard is 0.8, the height of the courtyard wall is 2.6 m, the courtyard gate is situated centrally, and the orientation of the courtyard is at an angle of 30° to the east.

(2) The regression analysis examining the interaction between various layout influencing factors and the wind environment of different courtyards indicates that the aspect ratio of courtyards and the height of courtyard walls are significantly correlated with the wind environment. Furthermore, the location of the courtyard gate demonstrates a correlation with the linear-shaped courtyard, while no significant correlation is observed with the L-shaped courtyard. Additionally, the orientation of the courtyard shows no correlation with either of the two typical courtyard types.

While the study yielded several significant conclusions, it is important to acknowledge certain limitations. The research focused exclusively on two predominant wind directions during the spring, summer, and autumn seasons, neglecting to incorporate an analysis of the winter wind environment. Additionally, the building model utilized was a simplistic block

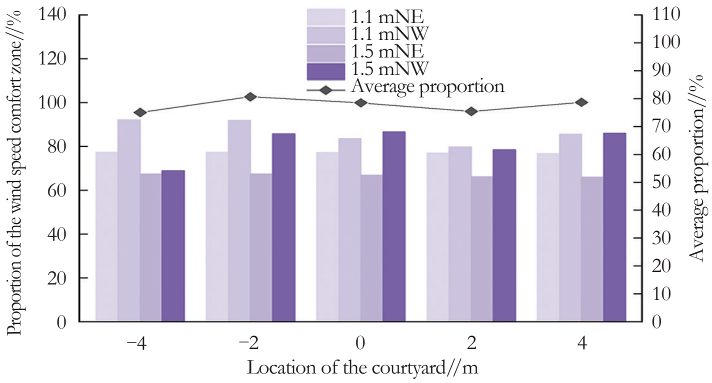

Fig.13 Proportion of the wind speed comfort zone across various locations of courtyard gate

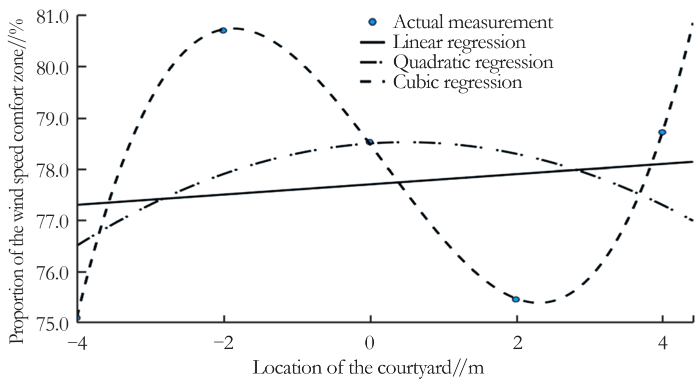

Fig.14 Regression analysis of average proportion and location of courtyard gate

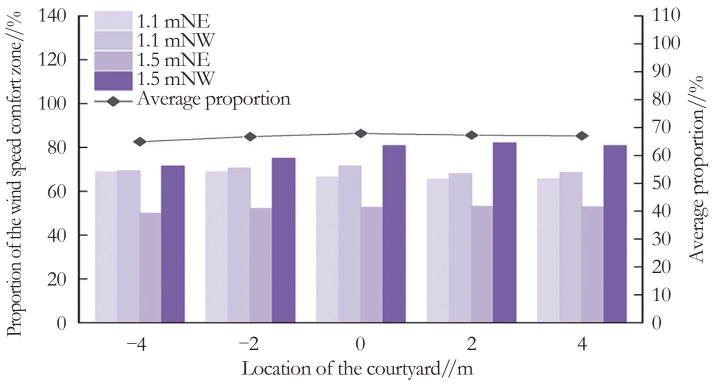

Fig.15 Proportion of the wind speed comfort zone across various locations of courtyard gate

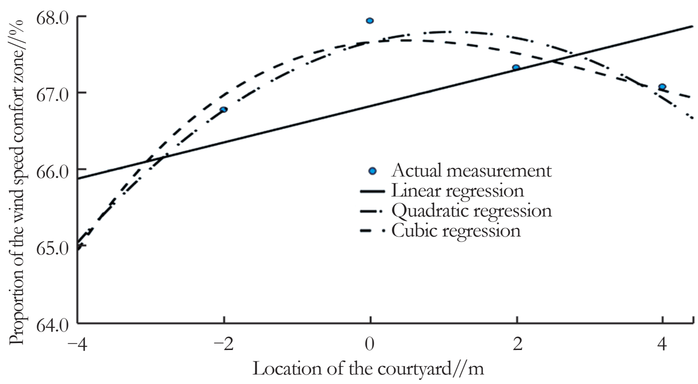

Fig.16 Regression analysis of average proportion and location of courtyard gate

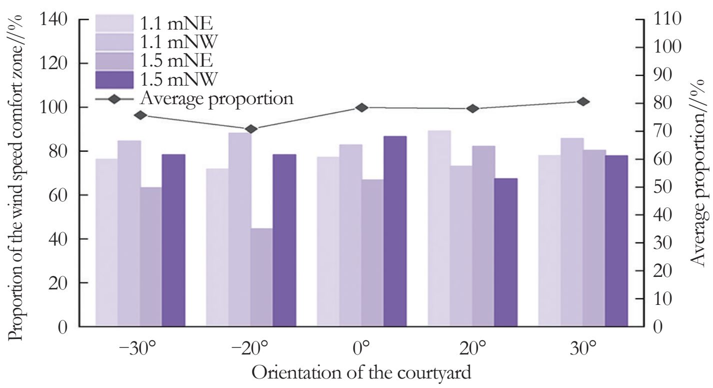

Fig.17 Proportion of the wind speed comfort zone across various courtyard orientations

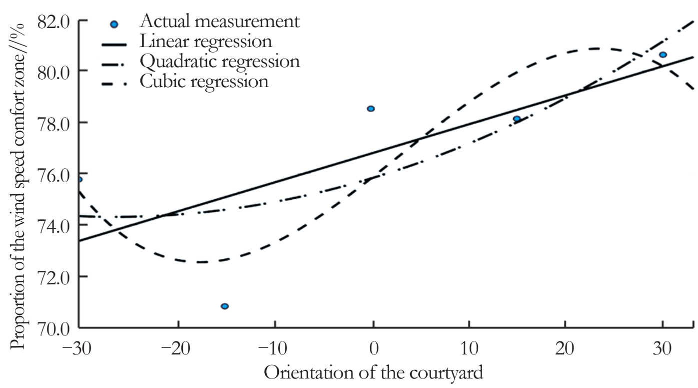

Fig.18 Regression analysis of average proportion and courtyard orientation

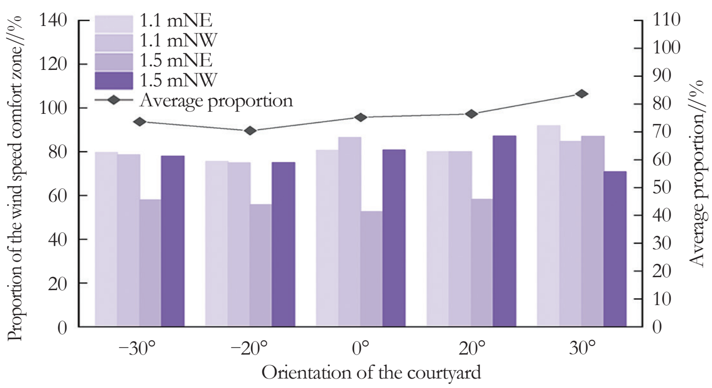

Fig.19 Proportion of the wind speed comfort zone across various courtyard orientations

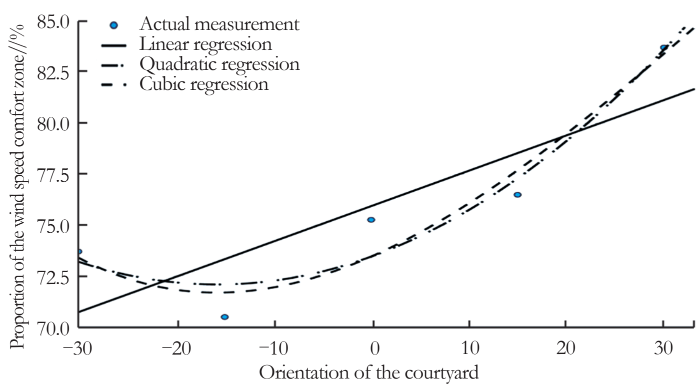

Fig.20 Regression analysis of average proportion and courtyard orientation

(To be continued in P18)

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representation, which failed to account for the interaction between indoor and outdoor wind environments, particularly in scenarios where windows are open. Consequently, future research should integrate the aforementioned two aspects, building upon the conclusions drawn from existing studies, such as simulations of the wind environment during winter under conditions of high-frequency wind direction. Such an approach will enhance the understanding of how layout factors in courtyards influence the wind environment. The aim is to gather more pertinent data regarding the wind conditions in rural courtyards, which will hold practical significance for the design of future courtyard spaces.

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