Comparison Of Wind Environment Adaptation and Street Space In Traditional Coastal Villages—— A Case Study Of Typical Coastal Villages In Fuzhou City

Tianyu Chen[1], Qiqi Liu[1], and Xin Wu[1,2*]

[1]School of Architecture, Fuzhou University, Fuzhou, China
[2]Jiangsu Province Engineering Research Center of Construction Carbon Neutral Technology, Suzhou University of Science and Technology,Suzhou 215011,China

Abstract. At present, most of the existing research on traditional dwellings focuses on their preservation and reuse, while their environmental adaptability is relatively underexplored. Especially in coastal areas, understanding and enhancing the environmental adaptability of buildings is crucial to guarding against natural disasters, protecting the ecological environment, maintaining socio-economic stability, and coping with climate change, all of which are key factors in achieving sustainable development. In this paper, two traditional villages in Fuzhou (Dinghai Village and Houguan Village), which have similar geographic environments but different types, are selected as examples to explore the adaptability of village street layouts and spatial patterns with different degrees of integration to coastal wind environments by analyzing and comparing them through CFD simulations.The study summarizes the conclusions through the horizontal comparative analysis: 1. the degree of spatial integration of the central street and the wind resistance of the village are positively proportional 2. the layout with high connectivity value and strong permeability of the space is conducive to the improvement of the village's wind environment adaptability. By comparing different village patterns, the article refines the spatial characteristics of streets and alleys for the wind adaptability of coastal traditional villages, with a view to providing certain technical support and theoretical basis for the protection and renewal of traditional villages in China, as well as for the strategic planning in terms of sustainable development.

1 Introduction

Fuzhou, the capital of Fujian Province, is located in the subtropical monsoon climate zone, where typhoons, heavy rains and other inclement weather are frequent, but a relatively large number of ancient villages are still well preserved, which is evident in their good adaptability to the environment. At present, the protection and reuse of traditional houses mainly focuses on how to inherit and develop their spatial characteristics and core values. The academic community has already studied this issue, and mainly focuses on the simulation and comparison of the spatial forms and scales of the village as a whole, the village streets and the residential groups of the ancient villages, but the impact of the overall layout of the village and town streets on the wind environment is often insufficient due to the difficulty of controlling the variables. In this study, CFD digital technology simulation is used to compare the village street layout of Dinghai Village and Houguan Village in Fuzhou City, Fujian Province, for example, with the means of spatial syntax analysis. This study not only provides a more in-depth understanding of the design wisdom of traditional villages, better protection and utilization of traditional villages, but also provides new ideas for the design of new villages in terms of wind-friendliness.

2 Literature review

2.1 Research on wind environment adaptation in traditional Chinese villages

Wind environment, i.e., meteorological factors such as air flow, air pressure distribution and temperature and humidity conditions inside and outside the building, which directly affects the building's adaptability to climate change.

China's coastal areas north and south across the tropical, subtropical and temperate zones, the marine environment is complex and variable, frequent marine meteorological disasters on the coastal and island residents, coastal tourism crowd, sea-related employment of life and property safety has caused a serious threat.[1] Among them, typhoon is the most influential meteorological disaster in China besides drought, heavy rainfall and flooding.The cumulative number of typhoons that made landfall in China from 2011 to 2014 amounted to 28, with 470 deaths (missing) due to the disaster, and

* Corresponding author: fzutccom@126.com

the direct economic loss exceeded 316.35 billion yuan.[2] 2022 Among the various types of marine disasters that occurred, the most serious direct economic losses were caused by storm surge disasters, accounting for 99% of the total direct economic losses. Among them, there were six typhoon storm surge processes, with a direct economic loss of 1248.593 million yuan. [3] The windy weather in the coastal area often brings serious damage to the production life and buildings, and its architectural wind environment adaptability thus has a great impact on the residential form. [4]

Existing research on traditional architectural dwelling forms is mostly carried out from the perspective of dwelling construction and conservation planning, focusing on the selection and application of materials[5], construction techniques[6-7] and their morphological types[8] and ecology[9-10], conservation archives[11] and conservation planning models[12], village vitality[13] and landscape renewal, etc., with less in-depth discussion of the wind-heat environment. On the other hand, studies on the wind and thermal environments of existing traditional villages mainly focus on the simulation and comparison of spatial forms and scales[16,18] at the levels of village as a whole[14], village street[15] and residential groups [16-17], such as the simulation and comparison of wind and thermal environments of ancient towns in different seasons and under different working conditions by Wang (2012) with the "wind and air collection" as the starting point[14]. Zhao(2021) simulated the village wind environment under two different wind directions in winter and summer, and qualitatively summarized the relationship between the village street layout and the wind environment of the village[15]; Chen Fei (2009) analyzed the indoor and outdoor wind environment of the traditional buildings and the reasons for this condition through the on-site wind speed and temperature and humidity tests of the buildings in Shanghai Lilong and Zhouzhuang Zhang Hall[14],. In terms of the impact of different street layouts of the village as a whole on the wind and thermal environment, it is often under-discussed because the variables are difficult to control.

2.2 Wind environment simulation and building layout

At present, wind environment research in China mainly focuses on the study of specific buildings and the wind environment relationship between buildings, which is reflected in the study of building group layout through CFD simulation[19-22] or the study of indoor and outdoor humidity and heat environment [23-26].

The research on the layout of building groups mainly focuses on extracting the existing problems after analyzing the wind environment of the group layout and providing relevant solution strategies. Yang Li (2010) utilized CFD technology, combined with Shanghai climate data. Simulation of the wind environment of a residential area in Shanghai, focusing on the simulation and analysis of the atmospheric flow field of the planning and design of the residential area, which has a guiding significance for the wind environment planning of the residential area[27]; Ma Shen (2017) put forward the optimization of the layout of a district in Changchun through the simulation of the wind environmen[21]; Lou Xiaoyang (2019) took the building groups of colleges and universities in cold areas as the research object, and through the variable control and comparative research method to propose optimization strategies for building groups based on wind environment simulation[22]; An Lining (2023) analyzed the wind environment of building surfaces using BIM models and Phoenics wind environment software, and derived energy-saving measures and energy reduction after simulating different energy-saving factors: window-to-wall ratios and thickness of thermal insulation panels with the control variables[28]; Shengxing (2023) paid attention to wind environment problems, simulated the wind environment in summer and winter, combined with pedestrian comfort, summarized the characteristics and problems of the wind environment of the university, and proposed optimization strategies to provide a reference for the design of the wind environment of the campus[29].

Research on indoor and outdoor humid and hot environments is mainly based on building monoliths or groups of buildings with similar spaces. Ruo-Jing Dong (2020) took the representative building of western Hunan as the research object, and clarified the influence of the spatial layout of building monoliths on the wind environment through the comparison of different plan forms and number of floors[30]; Yuping Li (2021) studied the atrium space of Lingnan multi-storey buildings, and paid attention to the influence of the parameters of its thermal pressure and ventilation on the thermal comfort in the building. thermal comfort in the building, to explore the conditions needed to create a more conducive to thermal pressure ventilation atrium[24]; Zhou Qinyuan (2023) selected an old residence in Xuzhou City to simulate and optimize the strategy of its indoor wind environment, and through the typology method, simulation analysis was carried out for different building types, and optimization of the design was carried out. [31]

The wind environment simulation in China mainly focuses on the overall layout of buildings and the ventilation optimization of single buildings, but there is little research on the wind environment of traditional coastal wind-resistant villages. The fact that coastal villages can survive in the harsh sea wind environment proves that their village layout has a unique organization and can effectively resist the harsh environment. However, its layout strategy has not been paid attention to and studied. Therefore, this paper conducts a comparative study of typical coastal villages in Fuzhou City, with a view to proposing passive energy-saving measures to form a group with good wind resistance by architectural layout techniques, saving energy and resources, and realizing green sustainability.

3 Research methodology

3.1 Case selection and data sources

Table 1. Some traditional villages in Fuzhou.

Village name	area	Geographic location	Historical year
Changmen village	0.13 km²	Surrounded by river on one sides	600
Dinghai Village	3.12 km²	Surrounded by river on two sides	1700
Qinjiang village	0.6 km²	Surrounded by river on one sides	300
Houguan Village	2.7 km²	Surrounded by sea on two sides	1400
Chita village	6.4 km²	Surrounded by sea on three sides	300

By analyzing and comparing some typical traditional coastal villages in Fujian Province (Table 1). In order to ensure that the differences in the objects of the study are as homogeneous as possible, the selection of the objects of the study is based on the consideration of three major objective aspects, namely, area, geographic location, and historical year, respectively, supplemented by the overall spatial layout pattern of the villages and other relatively subjective factors. Eventually, after analyzing the comparisons, Dinghai Village and Houguan Village in Fuzhou City, Fujian Province are selected as research cases.

Dinghai Village was built near the sea, facing the water on three sides, and was affected by the wind environment and water environment, so it was subject to defense and strengthening measures in the Yuan Dynasty to enhance its windproof and wind-resistant properties. Houguan Village is relatively far away from the coast, built near the river, it is located on the riverside, has special location characteristics, and Dinghai Village shape is similar, but there is no windproof and wind-resistant design for its overall street layout through special techniques, so it is regarded as an ordinary type of village as a control. The overall study starts from the macroscopic settlement level, studies the wind environment of different villages through CFD simulation, and analyzes the relationship between the spatial integration of villages and their adaptability to the coastal wind environment by combining with the spatial syntax.

The epw format meteorological data from the China Standard Weather Database (CSWD) were accessed using ladybug during the study. These data cover 8760 hours of detailed climatic information of Fuzhou city in a year, including temperature, humidity, wind speed and solar radiation intensity. Compared with the traditional CFD simulation method, which relies on consulting relevant specifications or requesting data from the Meteorological Bureau, adybug is linked to the China Standard Weather Database (CSWD), which can provide more accurate data, and analyze and filter the meteorological data as well as visualize them, so as to obtain more accurate simulation results.

3.2 Simulation of computational fluid dynamics

Numerical simulation of computational fluid dynamics (CFD) plays a key role in the field of building wind environment simulation research. This method is based on the equations of fluid dynamics, through the analysis of the wind field and thermal environment in the building and its surrounding environment, to realize the detailed analysis of complex building models.CFD technology through numerical simulation and visual means of expression, making it possible to compare and analyze a variety of influencing factors, so as to effectively improve the quality of the design of the wind environment of the building and to reduce the economic investment required for the experiments [32].

At present, there are many kinds of CFD simulation software for wind environment simulation in the engineering field, such as Fluent, Airpak, Pheonics, Windperfect, Star-CCM+ and so on. For a variety of CFD wind environment simulation software, the simulation software used in this study is PHOENICS, which is characterized by more direct parameter setting, semi-automatic grid division, and more efficient, fast and intuitive data results. Therefore, PHOENICS is mainly used for wind environment simulation in this design[18].

4 Simulation results

In this paper, Dinghai Village, Houguan Village, and Dinghai Village in Fuzhou City are taken as the simulation objects, and the surrounding natural shields such as fences and slopes that will affect the simulation of the wind environment of the buildings as well as the internal buildings are modeled and then imported into the Phoneics software for analysis, respectively. According to the range of calculation area recommended by AIJ, the horizontal boundary of this simulation is the horizontal range centered on the target building with a radius greater than 5 H, and the upper calculation area is greater than 3 H. Since all three villages are close to the river and the sea, the value of 0.1, recommended by AIJ [33], is chosen for the ground roughness selection for the simulation and analysis by the software[18]. Because the simulation grid setting has a large impact on the accuracy and stability of the computational analysis, the number of grids in the external simulation range is appropriately reduced and the number of grids inside the villages is increased in the grid setting. The overall grid distribution shows a more uniform gradient state to ensure that the overall grid size is consistent. The number of grids is controlled at one grid per cubic meter during simulation.

After importing the meteorological data epw file of Fuzhou city, the calculated flow rate can be found by using the post-processing function of the software, and the calculated flow rate of each simulation is examined for the error, and the flow rate error is within 0.2%, and the simulation results can satisfy the requirements of this test, so it can be seen that the simulation of the grid setup is feasible.

By analyzing the wind environments of ordinary villages and coastal defense villages, CFD software is used to simulate the wind environments of Houguan Village and Dinghai Village for several times, and the analysis and comparison are as follows:

4.1 Macro differences

Observing the overall pattern of the two villages (Fig. 1 and Fig. 2), Houguan Village exhibits lower street and building densities compared to Dinghai Village, resulting in a smaller proportion of internal quiet wind zones and a relatively high average wind speed. Due to its complex street network and higher building density, Dinghai Village is able to effectively regulate the wind flow and create a more comfortable and safe pedestrian environment. In contrast, Houguan Village's simple layout and lower building density result in its weaker ability to regulate wind flow. This difference reflects the different considerations of wind environment adaptation in the village planning of the two villages.

The overall wind speed of Houguan Village is higher than that of Dinghai Village, mainly because the overall sense of enclosure of the street space is weaker, which can not effectively limit the wind speed and direction. The weaker sense of enclosure means that the internal ventilation is stronger, but the wind resistance is weaker than that of Dinghai Village, which also makes the performance of the village not as good as that of Dinghai Village in withstanding strong winds, and the difference reflects the difference in spatial structural emphasis between the two villages due to the different geographic locations.

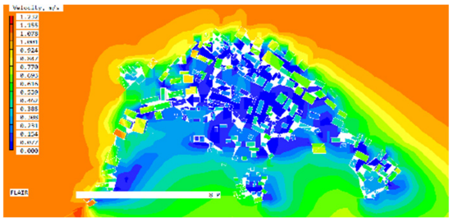

Fig. 1. CFD simulation results of Houguan Village.

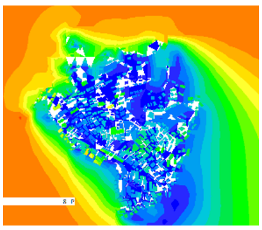

Fig. 2.CFD simulation results of Dinghai Village.

4.2 Difference in street integration degree

Applying Depthmap to carry out spatial language analysis, we analyze and integrate the spatial patterns of streets and alleys in Hau Guan Village and Ding Hai Village in terms of global integration degree and connection degree.

In the spatial language analysis conducted by Depthmap (Fig. 3 and Fig. 4), the difference between Dinghai Village and Houguan Village in terms of street integration degree is significant, and the analysis study found that: the spatial integration degree of the center area of Dinghai Village is higher, and because of the many side streets, the integration degree of its different streets varies greatly, and the integration degree decreases along its structural hierarchy at a relatively slow speed. Combined with its spatial design and street windproof layout, it can be seen that more side streets can disperse airflow and reduce wind speed, and the density of surrounding buildings can also enhance the windproof performance of the street space. This street layout makes the wind flow more evenly distributed in the village and reduces the impact of strong winds on specific areas. This street network not only disperses the airflow, but also improves the uniformity of wind speeds within the village, thus reducing the potential damage to the village interior from strong wind events and contributing to improved air quality and pedestrian comfort.

In contrast, Houguan Village has a much simpler structure with a well-defined street network that results in a rapid decrease in integration along its structural hierarchy. This simple street layout, while potentially aiding traffic flow and village navigation in some respects, exhibits certain deficiencies in terms of wind environment resilience. Particularly in strong wind conditions, the lack of sufficient side streets and the complex street network may result in wind speeds that are too high in some areas, increasing risks to buildings and pedestrians.

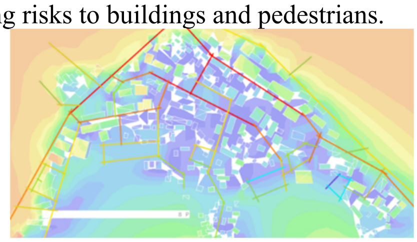

Fig. 3. Global integration degree and wind environment analysis of Houguan Village.

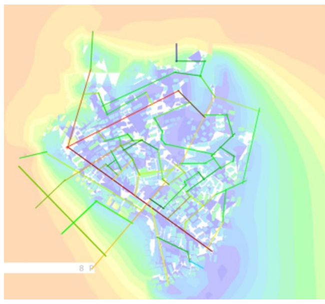

Fig. 4. Global integration degree and wind environment analysis of Dinghai Village.

4.3 Difference in street connection value

Comparing the street connection value of Houguan Village and Dinghai Village (Fig. 5 and Fig. 6), it can be seen that the connection value of Houguan Village's internal streets and alleys is 2-5, and the connection value of Dinghai Village's internal streets and alleys is 2-8. On the whole, the connection value of Houguan Village's streets and alleys is lower than that of Dinghai Village's streets and alleys, which is mainly due to the fact that it has too few internal bypasses, and relies on the main axial roads to connect up the overall layout, so that the accessibility to different streets and alleys has decreased. For the analysis of its users, due to the fact that its internal branch roads are fewer and basically lead to the residents' own houses, the tourists seldom use the branch roads and mainly use the main axial roads to pass through, which results in the lower connectivity value; at the same time, the internal roads in Dinghai Village are well-connected, and the boundaries between the residential houses and the public buildings are not strong, which greatly enhances the connectivity value of the streets and alleys.

Through the comparative wind environment simulation analysis study, it was found that:

Ordinary traditional villages are weaker than coastal villages in terms of wind protection, firstly, due to the relatively simple structure of their road network, which lacks the good detachment and bifurcation of branch roads to wind and airflow; secondly, their building density and the degree of enclosure around the streets also have a greater impact on their wind environment. Therefore, some branch roads can be used in the windproof design of ordinary traditional villages, which is not only conducive to windproof design, but also can create diversified space and increase the connectivity and accessibility between different roads.

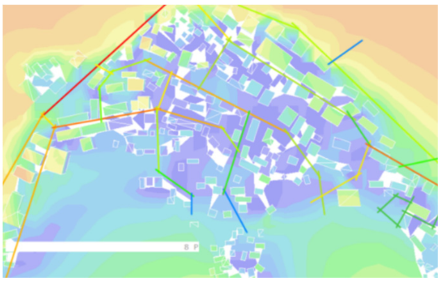

Fig. 5. Connection values and wind environment analysis of Houguan Village.

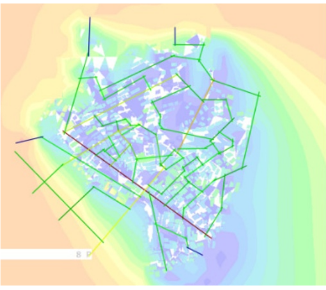

Fig. 6. Connection values and wind environment analysis of Dinghai Village.

4.4 Simulation of village spatial structure optimization scheme

According to the above analysis, appropriately increasing the building density of the village and adding branch roads between streets and lanes can affect the spatial integration and connectivity value of the village, which in turn affects the wind resistance performance of the village.

In order to verify this idea, we re-conducted the simulation experiment and compared the results with the original simulation based on Houguan village after increasing the building density and adding some branch roads. (Fig. 7 to Fig. 9) The results show that the overall spatial integration and connectivity of the village has been improved compared to the previous one, and the wind resistance of the village has also been enhanced to some extent. Meanwhile, due to the addition of branch roads, winds of appropriate sizes can enter the village, and the overall wind speed of the village is more uniform, which improves the comfort of the wind environment in the streets and prevents the deposition of dirty air while satisfying the needs of the residents.

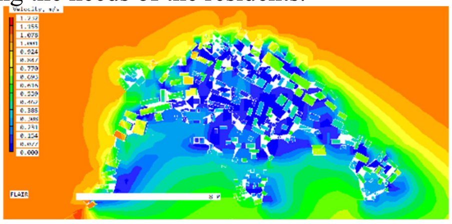

Fig. 7. CFD simulation results of optimized Houguan Village.

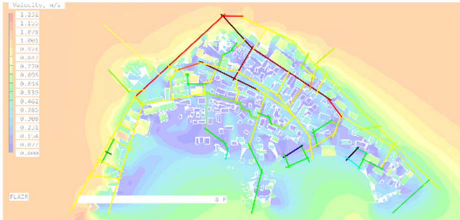

Fig. 8. Global integration degree and wind environment analysis of optimized Houguan Village.

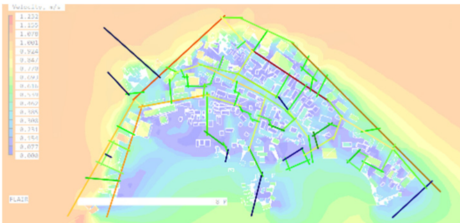

Fig. 9. Connection values and wind environment analysis of optimized Houguan Village.

5 Conclusion

This paper conducts an in-depth exploration of the differences in wind environment adaptability between Houguan Village and Dinghai Village in Fuzhou through computational simulation comparisons, and comprehensively analyzes the relationship between village spatial morphology and wind environment from the perspective of space syntax. The conclusions of the study are as follows:

1. Under similar conditions, the presence of more branch roads in the road network can enhance the spatial integration of the central streets, thereby strengthening the village's wind resistance. This effectively mitigates the negative impact of excessive wind speed on the streets in harsh wind environments.

2. The multi-level, multi-centric aggregation core pattern of traditional coastal villages endows their streets with high connectivity and good permeability. The resultant centripetal characteristics significantly benefit disaster prevention and environmental adaptability.

The traditional coastal dwellings encapsulate the wisdom of ancient people. The attention and research on ancient coastal dwellings should not be limited to their preservation; the experience of their adaptability design to the local climate environment requires in-depth study and heritage application. This paper, through its research on the relationship between street space and wind environment in traditional villages, proposes the aforementioned conclusions, aiming to provide more references and inspirations for future sustainable urban and rural planning, to achieve a harmonious coexistence between humanity and the natural environment.

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