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Research Article

Study on the Wind Environment of the Architecture Communities: Traditional Typical Min Nan Human Settlements' Case

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In contrast to the modern urban planning, which can be done in short period in terms of the spatial qualified design, the traditional tribe needs longer period in terms of the villagers' sense of community. The selection of location, planning, and construction reveals the wisdom of the former people's use of the resourceful life experience. First, the paper employs PHOENICS to simulate the wind environments of two most representative patterns of rural settlements in the southern area of Southern Fujian, China. This was made to compare the different conditions caused by settlements of various architectural groups. Second, the engineering and construction aspects of settlements—such as the width of roads and building structures—will be further analyzed and examined as case study in attempt to discover the favorable environmental factors for generating winds as well as the construction dimension of the settlement, such as the road width and the architectural design. Finally, the paper tends to conclude with an energy conservation strategy applied to the construction of modern communities which has low density and small group buildings.

1. Introduction

The worldwide environmental deterioration and the energy and resource crisis have recently attracted widespread attention among the people around the globe. The construction of the architecture always needs to consume a great amount of regular resources. Hence, how to make the best use of the natural renewable resources to reduce the consumption of energy in building has become the main task in the architectural design circle. In the past, most research was devoted to the building and its subsidiary environment. Rarely was the research conducted to discuss how to use the natural energy—such as the wind power—in the construction dimension of the settlement. On the other hand, the research was usually pertaining more to the overall energy conservation measures in the traditional settlements based on their experiences, and less to a comprehensive research of quantitative calculation. The reasonable layout of building groups in modern residential district is conductive to the formation of good natural ventilation environment and regional climate in cities [1, 2]. Based on the CDF method, this paper provides analysis on the relationship between traditional settlement wind environment and microclimate environment [3–5] and discusses the construction of residential district in modern cities from the perspective of architecture and urban design.

1.1. Research Objects. Under the cultural background which includes immigration history, there are two most representative patterns of rural settlements in Southern Fujian, China: determinant-ordered structure and circular-spread structure. Detriment-ordered structure values the defensive functions of building and mainly forms building groups with orderliness in the spacious plains to form enclosed spaces. for the example of determinant-ordered structure, see Dai Mei Village, Longhai Country, Zhangzhou City, Fujian (Hereinafter referred to as Village A) in Figure 1.

Figure 1: Dai Mei Village. (source: Google map).

Figure 2: Hillside Village. (source: Google map).

Circular-spread structures mostly appear in the hillside section and the central loci of Circular-spread structures are ancestral hall and temple (Figure 2). The living building gradually spread from the central loci, which values the worship of ancestors and gods. To see the example of circular-spread structure; see, Hillside Village, Longhai Country, Zhangzhou City, Fujian (Hereinafter referred to as Village B) in Figure 1. These two patterns of settlement spaces are derived from different historic background and thus could express obvious meaning of cultural identity.

1.2. Research Methods and Steps. PHOENICS serves more as commonly-used software, less as software specifically used; it is widely applied for the calculation of "flow" and "heat" in various fields. Thus the optimization settings is the prime concern as the simulation of settlement patterns was put into application. The methods and steps can be summarized as follows.

(1) First, complete the environment setting before simulation, and then output the results of simulation and analysis.

(2) Compare the function of wind environments.

(3) Examine the reason why certain villages offer good wind environment and good wind effects.

(4) Offer suggestions and strategies for modern living communities.

2. The Numerical Simulation and Calculation of Wind Environment

2.1. The Environment Setting before Simulation

2.1.1. The Selection of the Mathematical Model. The winds flowing within the settlements are sometimes incompressible and low-speed turbulence [6]. Hence, the standard and generally-used mathematic model was applied to the present research: $k-\varepsilon$ model. The advantages of $k-\varepsilon$ model are low costs of calculation tools, low fluctuation while calculation, and high accuracy [7]. According to Tao's research [8] on the numerical heat transfer, all controlled differential equation elements—including continuity equation, momentum equation, K equation, and ε equation—are defined as follows.

(1) Turbulent viscosity coefficient $\eta_t = c_\mu \rho k^2/\varepsilon$.

(2) Continuity equation $\partial(\rho u_i)/\partial x_i = 0$.

(3) Momentum equation $\partial(\rho u_i u_j)/\partial x_i = (\partial/\partial x_i)(\eta_{\text{eff}}(\partial u_j/\partial x_i)) - \partial_p/\partial x_j + (\partial/\partial x_i)(\eta_{\text{eff}}(\partial u_i/\partial x_j))$.

(4) K equation $\partial(\rho u_i k)/\partial x_i = (\partial/\partial x_i)[(\eta + \eta_t/\sigma_k)(\partial_k/\partial x_i)] - \rho\varepsilon + \eta_t(\partial u_j/\partial x_i + \partial u_i/\partial x_j)(\partial u_j/\partial x_i)$.

(5) ε equation $\partial(\rho u_i \varepsilon)/\partial x_i = (\partial/\partial x_i)[(\eta + \eta_t/\sigma_\varepsilon)(\partial_\varepsilon/\partial x_i)] - c_2(\rho\varepsilon^2/k) + (c_1\varepsilon\eta_t/k)(\partial u_j/\partial x_i + \partial u_i/\partial x_j)(\partial u_j/\partial x_i)$.

2.1.2. Selection of Physical Model. The traditional settlement architecture community is not high and is relatively smaller sized. The design of the architecture may lead to local microclimate, such as the space of courtyard and the shape of the roof. To reduce the statistical variations, the cubical model of the architect should be taken into consideration and made to undergo the configurative simulation model, especially the form of the slope roof which can easily cause impact on the direction of the wind. Hence, it is imperative that the model is necessary to as to obtain constructed in accordance with the original traditional roof form and design.

2.2. Simulate Wind Environments

2.2.1. Set Up Models. CAD was adopted to draw the 3-dimension substantial graphics of village pattern in STL format and introduce the graphics into PHOENICS (Figures 3 and 4).

2.2.2. Setting Up Climate Condition. The climate parameters about winds in the location of building groups were used as analogous boundary conditions (Table 2).

Table 1: Climate parameters about winds in Zhangzhou city.

City	Summer		Winter	
Zhangzhou city	Wind speed: 1.6 (m/s)	Wind direction: northerly winds	Wind speed: 1.6 (m/s)	Wind direction: southerly wind

Source: Practical design manual for heating and air conditioning (1st edition).

Table 2: The relation between human's feeling and wind speeds.

Range of wind speeds (m/s)	People's feeling
<1.0	Cannot feel any wind
1.0~5.0	Comfortable
5.0~10.0	Uncomfortable and the activities are influenced
10.0~15.0	Uncomfortable and the activities are severely influenced
15.0~20.0	Cannot tolerate
>20.0	Dangerous

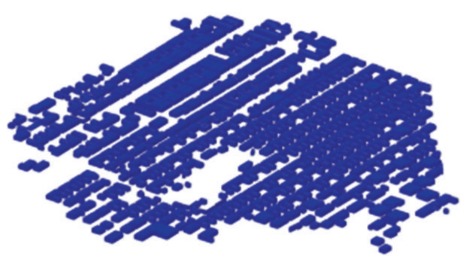


Figure 3: CAD3D model for Village A.

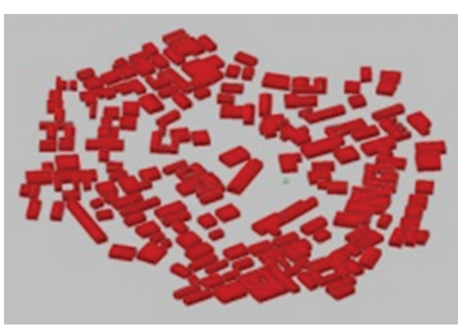


Figure 4: CAD3D model for Village B.

2.2.3. Comparison of Wind Environments. Consider the following.

(1) Introduction of the STL model (Figures 5 and 6).

(2) To adjust the size of calculated areas; the areas that buildings cover are smaller than 3% of overall areas of calculated region. First, targeted building was chosen as the center and made to set the height of building as H. The targeted building was used as the center and the region within a radius of 5H, which serves as the calculated region. The calculation area above the building proves greater than 3H.

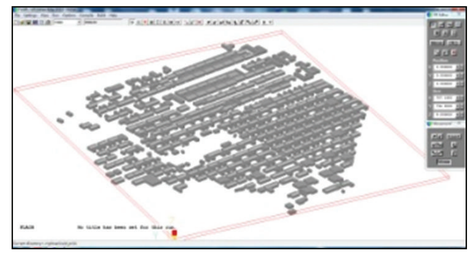


Figure 5: Model graphics for Village A.

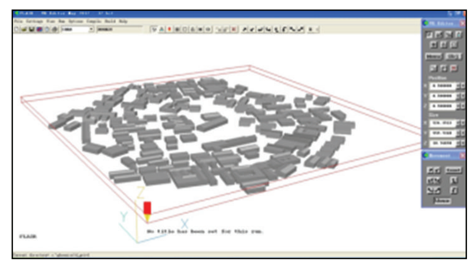


Figure 6: Model graphics for Village B.

(3) To adjust the amounts of grids. The appropriate grids were divided in terms of the side length of buildings. The key observation region mainly exceeds above the third grids and the higher grids counted from the ground (Figures 7 and 8).

(4) To set up parameters. "Calculation model", "Parameters for fluids", and "Calculation for step length" were set up (Figure 9).

(1) Calculation model. As the definition of controlled differentiation equation chosen in this project was concerned, KEMODLd was selected as the model of this research to undergo fluids calculation.

(2) Parameters for fluids. Physical parameters of the air flow such as pressure and temperature could be set in this interface.

(3) Calculation for step length. As the errors fall below 0.1% and the calculation come to convergence, the calculation ends.

(5) To set up the boundary conditions of wind environments. In terms of the wind speeds and wind directions of the two villages, this item was set and made. Wind speeds could be seen in Table 1, used to compare the different heat works of the two villages, which belongs to the hot summer and cold winter climate environment. The leading directions of summer

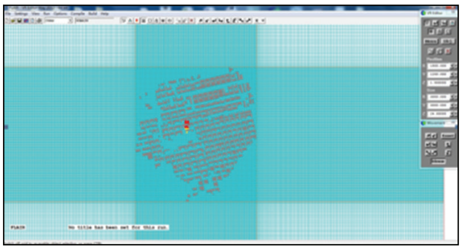


Figure 7: The grid setting of XY plane and Z axis of Village A.

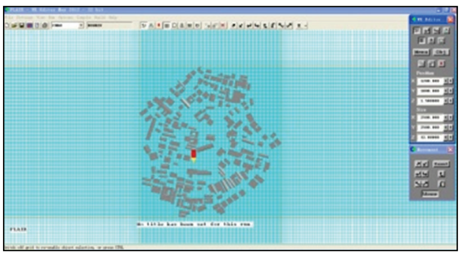


Figure 8: The grid setting of XY plane and Z axis of Village B.

Figure 9: Parameters for fluids.

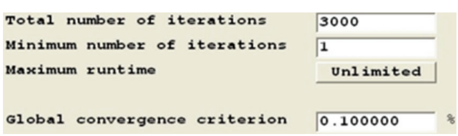


Figure 10: Calculate step length.

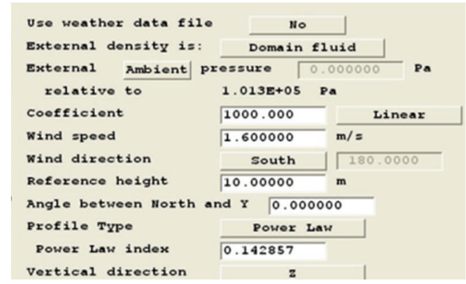


Figure 11: Parameters for winds.

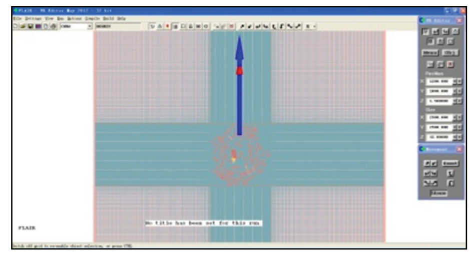


Figure 12: Direction of the wind.

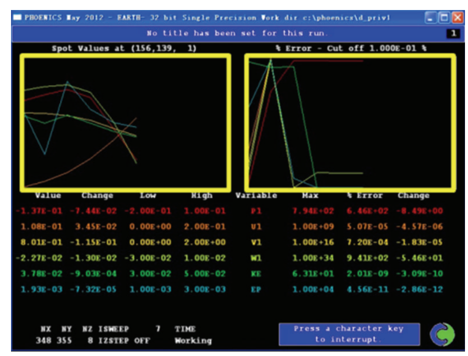


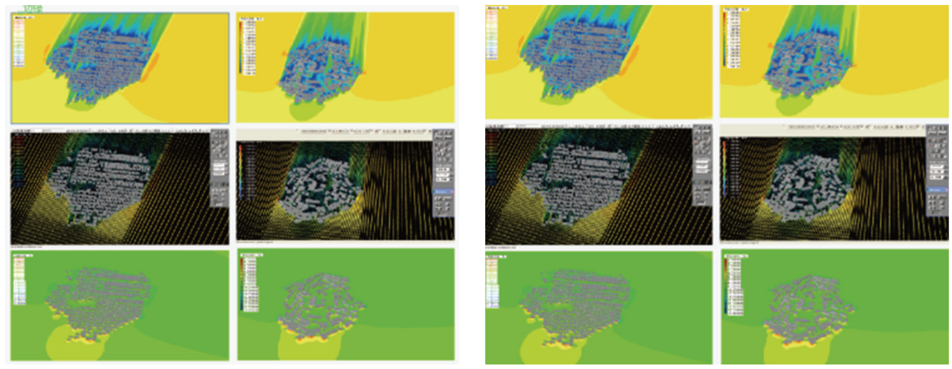
Figure 13: Solutions for calculations.

and winter to undergo calculations were thus chosen (Figures 10 and 11).

(6) Solutions for calculations. The Curve on the left frame demonstrates instant values such as wind pressure, wind speed, and so forth. The curve in the right frame suggests the curve of residuals after substraction. This indicates that the calculation results of this time minuses the calculation results of the previous time (Figures 12 and 13).

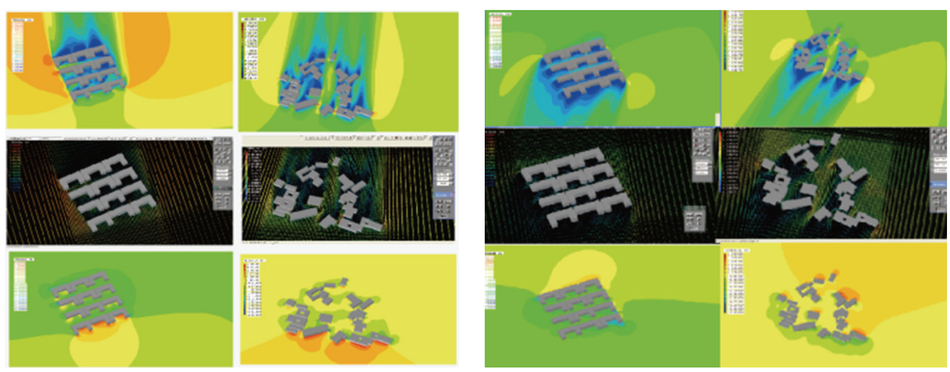
(7) Simulation results. The analog results could be divided into two parts. The first indicates that the village was regarded as the object of the overall wind environment (Figure 14). The second suggests that the local wind environment formed by certain buildings was taken as the object of the overall wind environment (Figure 15). Advantages of the two above mentioned parts could be separately demonstrated as well as mutually complementary. Bigger body mass and longer calculation periods are the two characteristics of the results in Part One. However, the results of Part One is easy for observing how the flow-in and flow-out direction of monsoons in the village exerts significant impact upon the formation of the whole wind environment as well as internal distribution of different wind field. The results of Part Two were easy for observing single building's inner and outer natural ventilation conditions influenced by wind environment.

2.3. Comparative Research. As the requirement of Evaluation Standard of the Green Building in Fujian(DBJ/T 13-118-2010) and the climate characteristics (hot summer and cold winter) indicate, summer and winter were chosen as the main seasons for evaluation. Assumedly, if the wind speeds of the pedestrian zone around the building fell lower than 5.0 m/s (1.5 meters in attitude, counted from the ground), it would not influence people's fundamental requirements about normal outdoor activities. The index for evaluating whether the natural ventilation of the outdoor of building group is the wind speed measured at 1.5 m in attitude counting from the ground. The fewer strong-wind regions with wind speeds higher than 5 m/s and lower than 1.0 m/s in the main entrance of the wind, the better wind environment would be defined in



(a) (b)

Figure 14: Simulation results about two villages' wind speeds and pressure influenced by summer monsoon and winter monsoon.



(a) (b)

Figure 15: Simulation results about the wind speeds and pressure of the two local typical building groups influenced by summer monsoon and winter monsoon.

the region (Table 2). As the standard of DBJ/T13-118-2010 and the color table with the unit values accessory to software system (Figure 16) indicate, the wind environments of village A and village B could be taken to access.

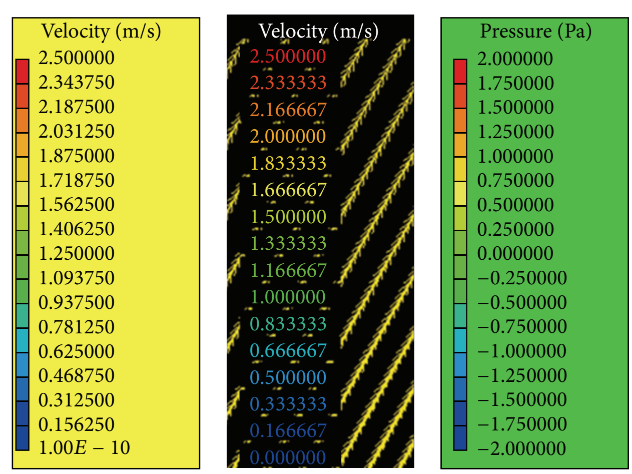
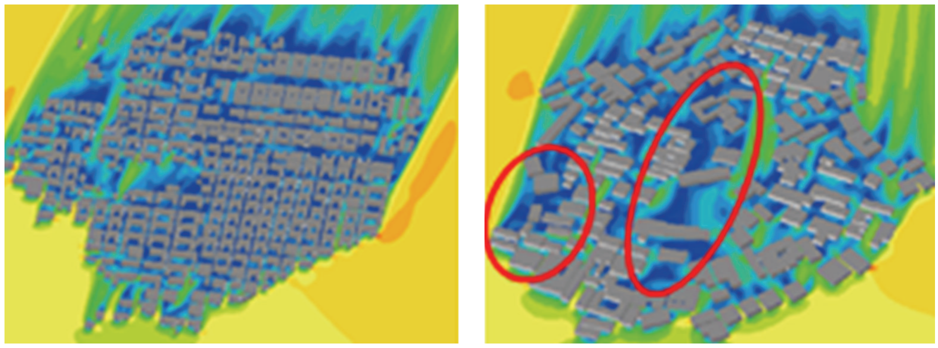


Figure 16: Units of wind speed, wind vector, and wind pressure.

2.4. Assessment on the Wind Environments of Settlements

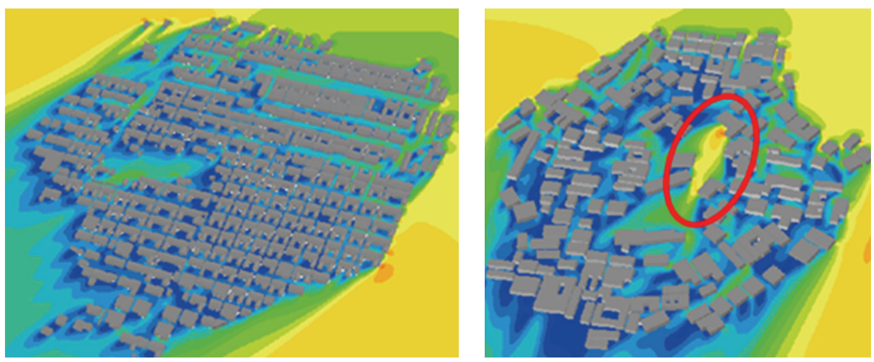
Wind Speed. As the winter monsoon of the prevailing wind direction is concerned, the highest wind speed in Village A is 1.1 m/s and the highest wind speed in Village B is 2.4 m/s; when considering the summer monsoon as the prevailing wind direction, the highest wind speed in Village A is 1.6 m/s and the highest wind speed in Village B is 1.5 m/s. Overall, both villages' wind speeds of outdoor pedestrian areas and activity areas in winter, summer, and transition seasons are lower than 5 m/s. Hence, the condition of natural ventilation is favorable and could live up to the requirement of comfort. Nevertheless, in contrast to village A, there are obvious differences between the calm zone (Figure 17) and strong wind (Figure 18) zone in village B. As the faces of the building in village B is irregular, part of the building groups face to the winter monsoon surface and back to the summer monsoon surface. Strong wind areas are more vulnerable to fire hazards.

Wind Direction. As there remain to be fewer differences between the wind vectorgraphs that show the wind environments influenced by the southern monsoon and the northern monsoon, as Figure 19 indicates, it is valid to suggest that, compared with village B, the variation of wind vectors in



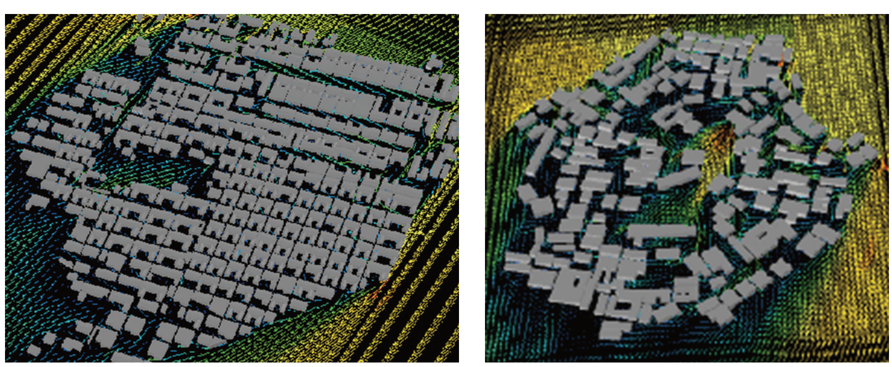
(a) (b)

Figure 17: Wind speed simulations of Village A and Village B in summer.



(a) (b)

Figure 18: Wind speed simulations of Village A and Village B in winter.

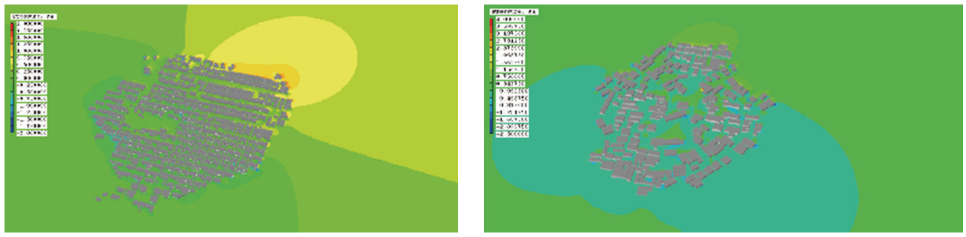


(a) (b)

Figure 19: Winter monsoon wind vectorgraphs of village A and village B.

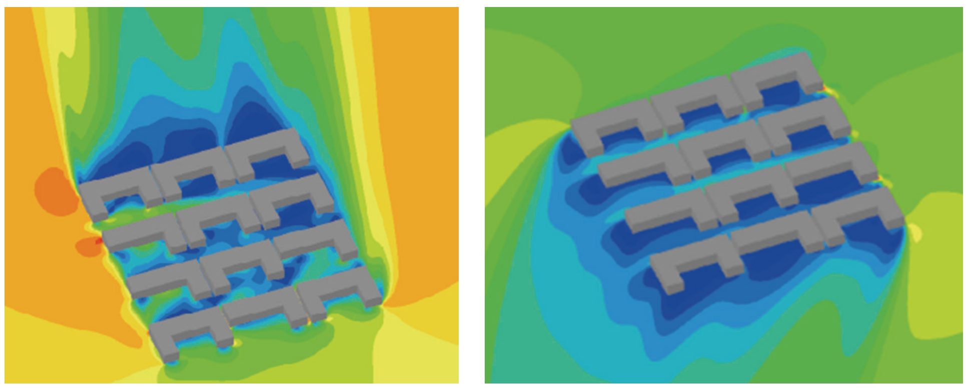
village A is smaller. Also, the trends of the air volumes rarely change and owing to the regular and ordered direction, it is easier for the guidance of wind direction. The trends of wind vectors in village B could be seen through the distinctions between the hierarchical color gradients, as there are obvious different hierarchies. The values of numerical differences fall between 2.5~0.15 and the wind direction diverge disorderly, which is against the indoor natural ventilation that takes advantage of the windward sides as gable walls.

Wind Pressure. As Figure 20 indicates, we could know that the in village A, the wind pressures in the northeast is higher and in village B, there are no high wind pressure areas. Nonetheless, high wind pressure values would not form strong wind areas and would form winds according to the pressure differences in the neighboring areas. Thus, according to the color table with the unit values, we calculate the differences between the neighboring wind pressures and find that village B is 1.0 Pa and village A is 0.3 Pa. Hence, there are higher



(a) (b)

Figure 20: Wind pressure graphics of Village A and Village B in winter.



(a) (b)

Figure 21: Wind speed simulations of the villagers A's building groups with determinant-ordered structures in winter and summer.

probabilities for village B to form cold and strong winds in winter.

2.5. The Outdoor Wind Environment of Building Group. Both the indoor and outdoor areas are the environments that villagers mainly use and are important venues for activities. The local wind environments formed by the building groups should be separately investigated to further understand the details of wind environments through observation data. The typical building group features determinant-ordered structures in village A and typical building group feature circular-spread structures in village B to undergo comparison analyses.

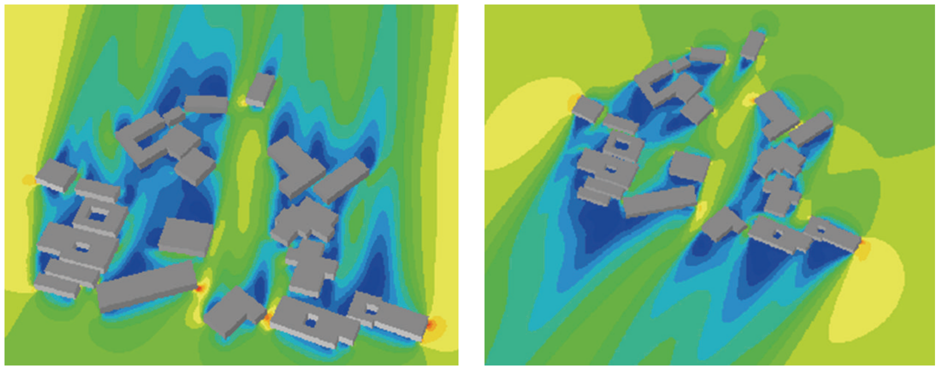
The choice of the building group case is considering the morphological features of the two typical settlements. So, the building group locates in the main inlet and outlet of the settlements and intensive distribution areas. Settlement A distributes with the same form of the building group, they have not manifest differences. Settlement B has a layout of reflection form, so we take the building group which is near the center position as an example, which have the structural features of the circle.

Wind Speed Graphics. The distribution of outdoor winter wind fields in the two villages and the highest wind speed is 1.6 m/s. The wind speed values in the main areas all situate within the range of feeling comfortable. There are obviously stronger winds in the center of the bag-shaped neighborhoods in village B and also fall within the comfortable range of 5 m/s. But, as the figure demonstrates, the configuration of building that contributes a lot to the formation of calm zones can be revealed. The building configurations of three-section compounds in village A are favorable to form the weak wind field in winter (Figures 21 and 22).

Wind Vectorgraphs. Consistent with the the overall wind vector graphics of the settlement, obvious differences remain on the trends and flowing amounts between Village A and Village B. The vector values of Village A are about 0.6 and the vector values of Village B are fluctuating between 0.2~2.0. In contrast to irregular structures, determinant-ordered structures are more likely to form gentle winds. The fluctuations of winds in Village B are relatively proven to be more obvious.

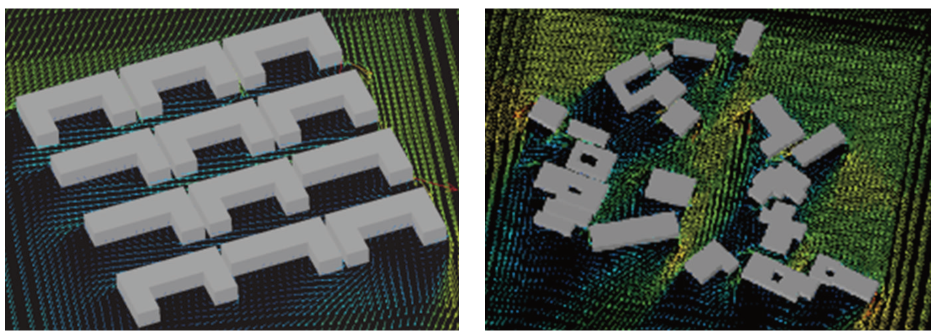
Wind Pressure. Research objects and neighboring environments pose great influences on the values of wind pressures. Thus, the intercepted spaces of parts of Village A and Village B does not appear proper to undergo wind pressure analysis; it is more proper for taking the overall wind pressure of the settlement as a premise (Figure 23).

2.6. Summary. A comparison can be recapped as follows. Village A forms better wind environments under the climate condition of Fujian and Minnan that characterize hot summer and cold winter. Determinant-ordered structures could control the gentle trends of wind vectors. The overall structures of the settlement are favorable to form the premise of



(a) (b)

Figure 22: Wind speed simulations of the villagers B's building groups with irregular structures in winter and summer.



(a) (b)

Figure 23: The winter monsoon vector diagrams of village A and village B.

Figure 24: The structures of Dai Mei Village, Longhai Country, Zhangzhou City, Fujian.

Figure 25: The broad transverse road in Dai Mei Village.

natural ventilation that flow across the buildings. The faces and configurations of the buildings are proven to be more difficult to form calm zones on the entrance surface of building in the winter. However, Village B's capacity for forming the calm zones is proven to be relatively weaker.

3. Spatial Pattern Analysis on Village A

Various definitions remain for space in different subjects. In this research, the space is the focus of the research, and it is formed by the construction and engineering. Hence, the investigation about the environments influenced by the artificial engineering such as the faces of the buildings and roads will be emphatically examined. In conducting the field work and making survey in Village A, the following points about the formation of wind environments in the settlement are accrued.

3.1. Street Structure. The structure of Dai Mei Village (Village A) is determinant-ordered, multilevel depth, and connected with organic environment around (Figure 24). The roads are wide in the front and narrow in both sides and with broader road in the southern side of the building, which ranges from 8 to 12 meters (Figure 25). The western side and eastern side of the roads are narrower, ranging from 1 to 4 meters (Figure 26).

In Minnan, prevailing northwest winds reign in winter and prevail over southeast winds in summer. In the attempt

Figure 26: The narrow longitudinal road in Dai Mei Village.

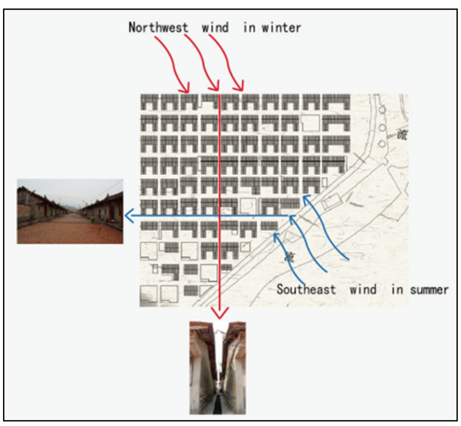


Figure 27: The relation between the monsoon in winter and summer and building style of settlement in Dai Mei Village.

of planning the construction of Dai Mei Village, the comb-styled structure of the roads was designed to guide the winds and to provide optimal capacity for the adaption of climate condition (Figure 27). The southeast sides are open and wide, which make it easy for the entrance of southeast monsoon in the summer and could lower the indoor temperatures through natural ventilation. The building structures in the northwest direction are relatively enclosed and are easy to reduce the entrance of cold winds from the northwest sides. This could also reduce the energy consumption for heat preservation in winter.

3.2. The Strategy for the Layout of the Building. The determinant-ordered structure in Dai Mei Village is favorable for guiding the entrance of the southern winds in summer. However, this form of structure remains too unitary for the building in the living communities. Thus, PHOENICS was adopted to simulate and calculate the wind environments formed by other structures derived from determinant-ordered structure (Figure 28). We find that the transversal dislocation and longitudinal dislocation favors the guidance of southeast winds in summer (Figure 29).

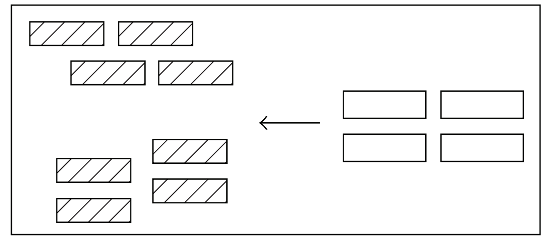


Figure 28: Two figures derived from determinant-ordered structure.

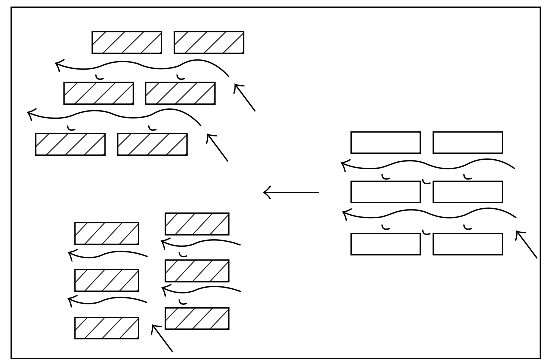


Figure 29: Simplified illustration about wind vector.

3.3. Architecture Forms. In Dai Mei Village, the distances between the buildings in the eastern and western directions make the streets narrower. The narrow streets surrounded by the two-sided high walls are commonly known as "ventilation lane" or "cool lane" [9]. In general, the walls would be exposed to the sunshine and would absorb lots of heat and would radiate heat to the indoor and thus cause the high temperatures in the indoor. But the intense built building in Dai Mei Village could shade each other and most of the walls in east-west direction basically are not influenced by the sunshine from the west, which could avoid the disadvantageous results caused by heat accumulation.

As the villagers in Dai Mei Village are consanguinity in the same clan, the relationships between the villagers are close. Consensus are made between villagers that every home would set a door on the end elevation of the building. Once all the doors on the end elevation of the building are opened, a circulating ventilation pipeline in east-west direction could be formed (Figures 30 and 31).

The configuration of higher front surface and lower back surface (Figure 32) is favorable to block cold northern winds and also form relatively weaker reflow winds. This proves to be advantageous for natural ventilation. Multiple layers of parallel-ordered buildings could form bigger areas for wind shadow and could influence the effects of natural ventilation.

3.4. To Build Altitude Strategy. The narrow distances between the walls of two building bring the access to the formation of the long and narrow ventilation space in northern-southern direction. This kind of building structures provides active ventilation, which could reduce the radiated heat from sun

Figure 30: The narrow ventilation lane is the best place to enjoy the cool air in Dai Mei Village.

Figure 31: There are doors in the east-west direction of all buildings.

and form the convection condition that connects the lanes and the indoor to make the living place shaded and cool. Of course, modern residences could not allow too close spacing or distance between building walls. Nevertheless, it is totally feasible to take advantage of the building groups for forming ventilation lane. It should be avoided to make the long axis of the house vertical to the prevailing wind direction in winter. By doing this, the negative effects caused by the front-row houses on back-row houses could be reduced and form good air convection (Figure 33).

4. Conclusion

By means of analog calculation of computing fluid dynamics, it is possible to suggest that the determinant-ordered structures formed by the engineering and construction of living houses and streets in Dai Mei Village could provide good natural wind environments. It is advantageous for the passing through of southeast winds in summer and the blocking the cold northwest wind in winter. To recap, the three main characteristics of the structures in the settlement are described as follows.

(1) Comb-Styled Structures. The neat and ordered streets are parallel to the prevailing direction in summer. While gusting, the narrow lanes and streets could enhance the wind speeds,

Figure 32: The altitude differences between the front and the back of the single building.

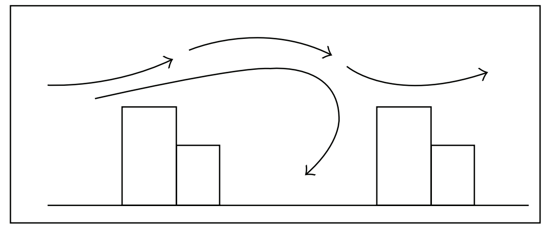


Figure 33: The altitude of the building groups in the community.

which is favorable for lowering the temperatures. Without winds, the high-intensity cold air in the shaded lane and low-intensity hot air outside the lanes would form convection and the convection. It could improve the heat environment of the living houses.

(2) High Walls and Narrow Lanes. The aspect ratio of narrow lane is huge and there are also eaves on the walls that could shade the sun to reduce temperature. Owing to the small areas exposed to sun and low-temperature air, the outdoor cool lane could thus be formed. Cool lanes are those wind paths with smaller cross-sectional areas. These cross-sectional areas could accrue the wind speed and lower the wind pressure. The hotter airs in the rooms connected to the cool lanes could be brought to the cool lane. The cooler air in the cool lane would supplement to the room, which could achieve the goal of ventilation.

(3) Southern Wind Hallway. The roads in front and in back of the house are broad and the lanes in both the right and the left of the house are narrow. This brings access to the southern winds to enter the south face of houses with three-section compound structure in summer.

Chinese modern city including office buildings, public buildings, and high-rise apartments tends to develop towards high-rise buildings. According to energy saving strategy of wind environment which this paper concerns, which is under the background of traditional low-rise residential areas, therefore, this design strategy is applied to local rural areas and urban villa residential areas.

5. Future Work

The results of the design strategy have already been transformed into a design program to take apart in the Residence Design Competition of Fujian village in 2009 (Figure 34); and the design program adapted from this research results was awarded with Excellent Planning Award and Champion of

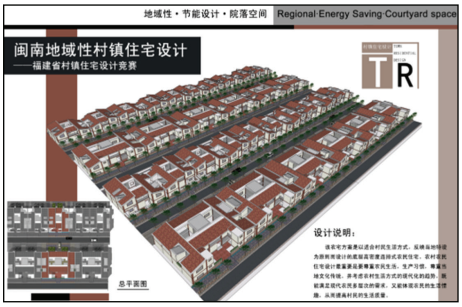


Figure 34: The design program of Minnan rural house in regions that is hot in summer and warm in winter.

Building category. The following research can investigate how wind environments influence the heat environment of settlements.

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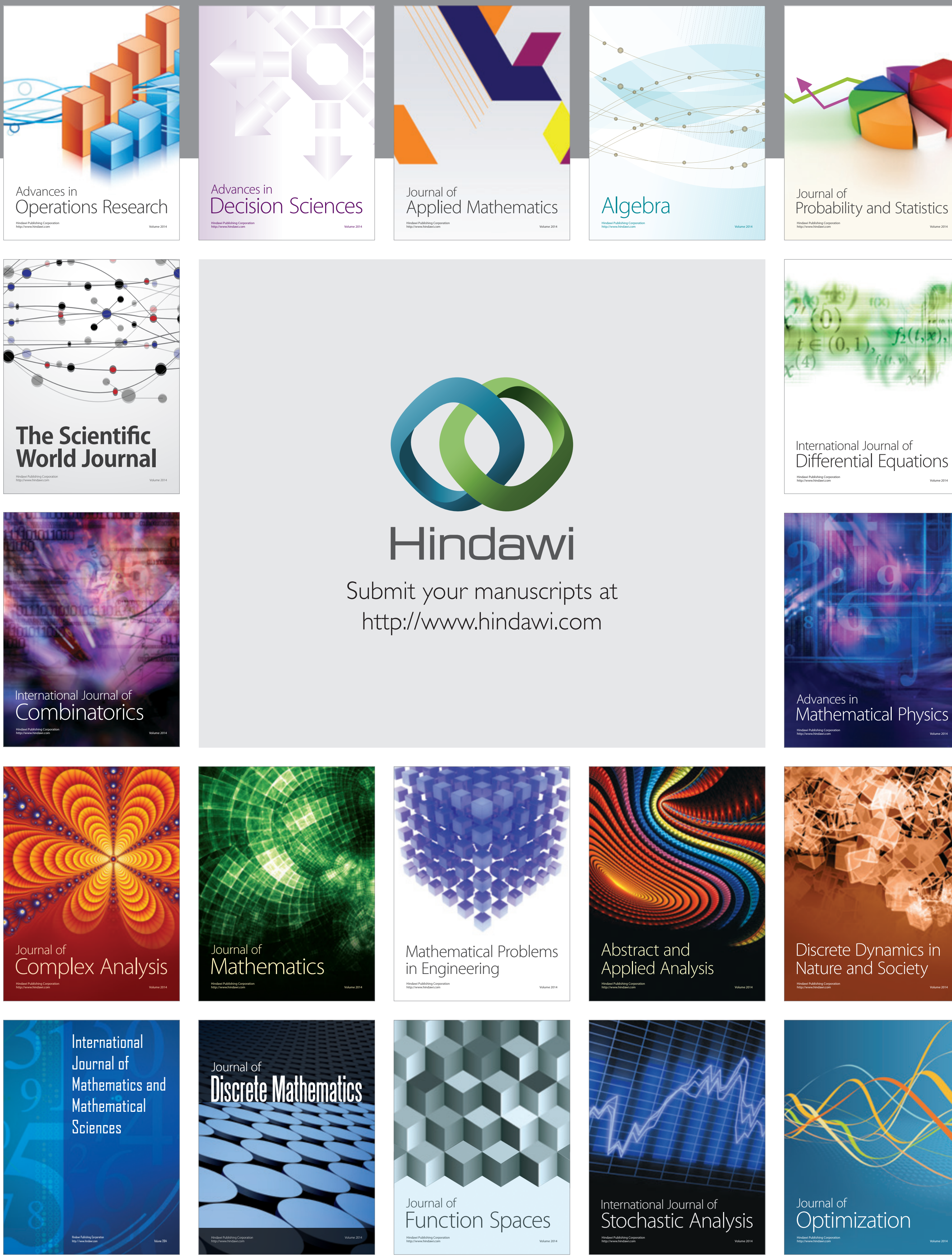
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