Air Ventilation Assessment – Study on Wind Pressure Ventilation System of Lingnan Vernacular Dwellings during Summer Time

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Abstract:

With the massive development of green building design and construction in Southern China, there exists a trend to draw lessons from Lingnan Vernacular Dwellings which are adaptive to a humid subtropical climate. Among those passive techniques, mechanism of ventilation within Lingnan Vernacular Dwellings have been widely studied and applied into practical construction during recent years. However, previous studies display inadequate outcomes of quantitative analysis or performance simulation considering the surrounding environment, which may lead to some incomprehensive viewpoints.

Combining performance simulation applying Computational Fluid Dynamics (CFD) with field measurement, the study conducts a ventilation assessment on a building with typical characteristics of Lingnan Vernacular Dwellings, meanwhile, surrounding area is also taken into consideration during the assessment.

Incomprehensive viewpoints regarding to the mechanism of wind pressure ventilation are refined. The study demonstrates that restraining natural ventilation is the main strategy of Lingnan Vernacular Dwellings during daytime while night time ventilation may have positive effect to boost cool air into dwellings. Patios work mainly as the air outlet which the air mainly flows from bottom to the upper area of patios, meanwhile, the combination between cold alleys aligning with north to south direction and doorways opening to west or east direction help wind pressure and thermal pressure ventilation concur at the same direction to breeze cool air into the patio. At last, it is revealed from the study that accuracy of simulation will be increased by taking the surrounding area into consideration, which is owing to the compact overall layout of Lingnan Vernacular Dwellings.

Keywords: Lingnan vernacular dwelling; Ventilation system; Summer time; Performance simulation.

1. INTRODUCTION

1.1 Learning from ventilation system of Lingnan Vernacular Dwellings in response to green building development in Southern China

Confronting with the massive development of green building design and construction in Southern China, designing with nature and local conditions have been widely accepted. As Lingnan Vernacular Dwellings symbolize the spirit of adapting to hot subtropical climate, which displays cultivated passive techniques regarding to air ventilation, sun shading and insulation, learning from passive techniques of Lingnan Vernacular Dwellings may benefit green buildings with higher efficiency of energy saving.

For a better utilization of passive design strategies which are learnt from Lingnan Vernacular Dwellings, questionable viewpoints on Lingnan Vernacular Dwellings will be argued in this study.

1.2 Former studies demonstrating enhancing air ventilation and mitigating heat gain as distinguished features of Lingnan Vernacular Dwellings

Lingnan Vernacular Dwellings is a unique term, which indicates that only architectures with features of Lingnan regional cultural and climatic characteristics rather than just architectures being built in Lingnan Region (LU, 2005). Geographical and climatic situation have strongly influences on Lingnan Architecture（LU, MA, DENG, 1981）. Most parts of Lingnan Region locate in subtropical area in Southern China where are characterized by abundant sun duration and irradiance as well as hot and humid accompanied by occasionally rainstorms and typhoons, meanwhile, prevailing wind direction during summer is southeast and south.

Previous studies on Lingnan Vernacular Dwellings involve aspects including the adaptation to local climate, cultural and humanity characteristics, features and details, as well as history and new development. However, enhancing air ventilation and mitigating heat gain are two of the most essential techniques among Lingnan Vernacular Dwellings (LU, 2005). Adaptive strategies to climatic issues that are mentioned above can be listed as below: (a) comb Style Layout and Compact Layout; (b) air ventilation system with the integration of hall, patio and alleyway; (c) building with nature; (4) facades and details that integrate climatic adaptation and humanity consideration（LU, MA, DENG, 1981）.

Among those strategies the well-organized overall layout is essential to the ventilation of Lingnan Vernacular Dwellings, Comb Style Layout and Compact Layout **(Figure 1)** are two of the most typical forms of overall layout for Lingnan Vernacular Dwellings, which help create better wind environment as well as thermal comfort for the residences. Meanwhile, the differences of temperature between cold alley, patio and other spaces of vernacular dwellings induce fluent air exchange even during the hot weather.

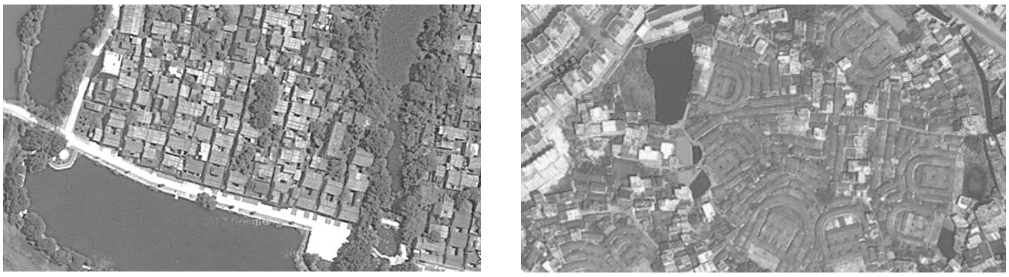


Figure 1. Diagram showing Comb Style & Compact Style Overall Layout
Source: Google Map

1.3 Former studies demonstrating the efficient ventilation system of Lingnan Vernacular Dwellings to enhance thermal comfort

With the corporation of hall, patio and alleyway, air ventilation system **(Figure 2)** is essential to create thermal comfort for people living in Lingnan Vernacular Dwellings.

Figure 2. Diagram showing the ventilation system combining patio, corridor, hall and alleyway
Source: LU Yuanding. (2005). Lingnan Humanity · Characteristics · Architecture. China Architecture & Building Press

There are two basic ventilation mechanisms of Lingnan Vernacular Dwellings including thermal and wind pressure ventilation. For the thermal pressure ventilation, the differences of air temperature among interior, patio, corridor, cold alley and surrounding areas lead to the variation of air density, hence, natural ventilation is generated owing to the exchange of hot and cool air. The mechanism mentioned above can be seen in the overall layout in most traditional villages of Lingnan Region. For instance, air temperature during daytime will decrease once the air flows through the surroundings which include ponds, farmland and trees of a village, meanwhile, building complex can be seen as the space with higher temperature so that exchange of warm and cool air is generated. As to the wind pressure ventilation, there exists demonstration that the patio works as air inlet owing to higher wind pressure. To be specific, air flows from the upper area into the patio, and then flows through the corridor and hall owing to lower wind pressure. Vernacular dwellings applying compact overall layout are examples displaying the mechanism of wind pressure ventilation **(Figure 3)**.

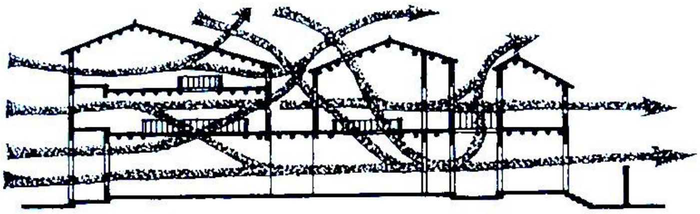


Figure 3. Diagram showing the mechanism of wind pressure ventilation
Source: LU Yuanding. (2005). Lingnan Humanity · Characteristics · Architecture. China Architecture & Building Press

1.4 Latest studies applying computer-aided performance simulation

There mainly exist two methods which are applied in the experiments of wind simulation including wind tunnel and computer-aided simulation. However, owing to the high cost and long cycle of wind tunnel experiment, CFD modelling which obtains a much shorter cycle and a more visualize result helping understanding is becoming more and more popular during the processes of architecture design. Combining CFD modelling and vernacular dwellings design is an innovation which help prevent the uncertainty of qualitative evaluation as well as increase the efficiency of performance simulation (LIN, WANG, ZHAO&ZHU, 2002). And computational results was verified by wind tunnel experiment in the Gilin Temple Project which indicated that the simulation results in CFD and testing data in wind tunnel experiment agree with each other(TSOU, 2002).

As to Lingnan Vernacular Dwellings, there have been a few performance simulation studies by applying computer aided simulation and actual measuring on a single building **(Figure 4)**, showing that the scale of patio space has the core value in climate adaptability of typical Lingnan Vernacular Dwellings, and reasonable range of scale in patio space is testified(XIAO, LIN, 2012).

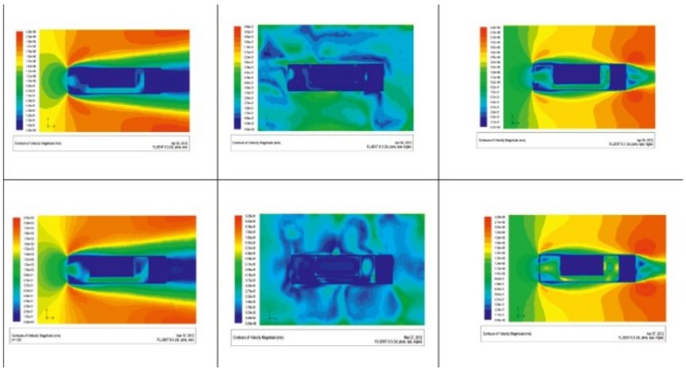


Figure 4. Diagrams showing subject site and result of simulation

1.6 Summary

Though former studies have been made during last few decades, inadequate performance-based simulation has been done regarding to microclimate assessment on Lingnan Vernacular Dwellings, and there are more qualitative analysis on the air flow direction rather than quantitative evaluation which may lead to questionable viewpoints such as: (a) good natural ventilation is the main reason for vernacular dwellings to keep cool during daytime in summer; (b) patio may work as air inlet or outlet depending on various circumstances.

As one of the alternatives for the studies on Lingnan Vernacular Dwellings, computer aided simulation may be efficient, reliable and sustainable, however, former related studies on Lingnan Vernacular Dwellings are mostly focus on single building rather than architectural complex which may lead to results with more residuals.

1.7 Objectives of the study

Combining actual measurement with performance simulation applying CFD modeling to assess the air ventilation among certain building complex of Lingnan Vernacular Dwellings, objectives of the study are: (a) to testify the general pattern and air flow direction of the wind ventilation at a scale of building complex among Lingnan Vernacular dwellings; reported by using Wind Velocity Ratio(VR) and Wind Velocity Vector(VV); (b) to further refine that restraining natural ventilation is the main design strategy during daytime while wind pressure ventilation only has the aiding value to enhance a better indoor thermal comfort during daytime in summer; (c) to further summarize the understanding of wind ventilation systems within Lingnan Vernacular Dwellings (good design features and problems); and (d) to further propose the advantages that can be taken during green building design and construction processes.

2. METHOD

2.1 Project assessment and surrounding Areas

The subject site locates in Langtou Village of Canton, Guangdong Province, which is listed as "China Traditional Village" on Feb 19th, 2014 published by State Administration of Cultural Heritage. Overall layout of the village can be characterized as Comb Style with low rise vernacular dwellings and ponds scattered to the surroundings of building complex.

Figure 5 is provided to demonstrate the modeled area which combines the study area with the surrounding area (with scale).

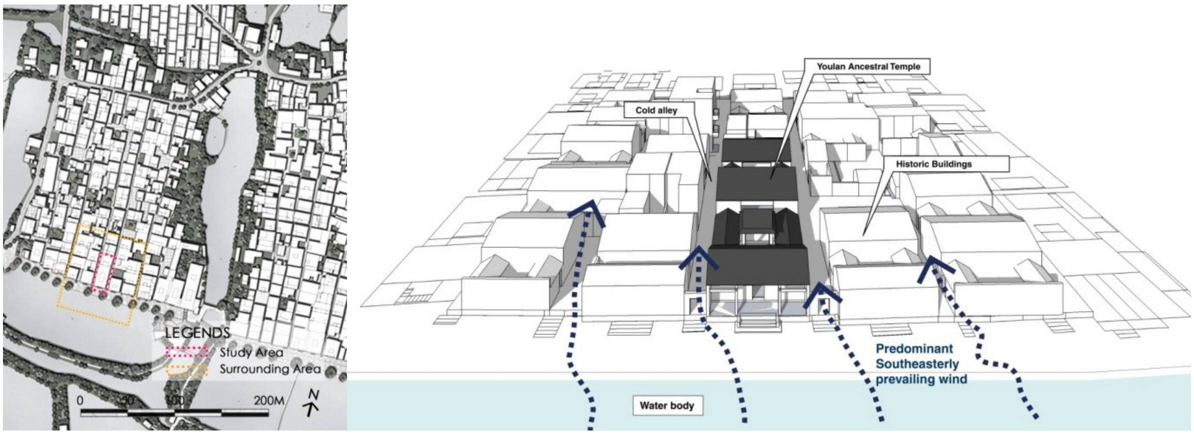


Figure 5. Diagram to demonstrate study area and the surrounding area

As shown in the diagram, most of buildings are aligned in the North to South direction which is organized along alleys with a width of 2 meters. Building heights are ranging from 4 meters to 7 meters. Most buildings within the surrounding area are historic buildings with brick-wood construction. Open space locating in this area is a pond to the South of the building complex.

2.2 Wind environment

The site where assessment areas locate is characterized with southeast prevailing wind direction during summer, on the contrary, north winds is dominant during winter. Since mitigation of heat gain is the major concern for Lingnan Vernacular Dwellings, prevailing wind direction during summer will be chosen for the wind environment of the study which is southeast at 157.5 degrees. For simulating the existing wind environment, "Computational fluid dynamics" will be the theoretical support to the study.

2.3 Performance simulation

Mesh of the model for the performance simulation in CFD is generated by Harpoon V4.3, ANSYS FLUENT 14.0 is applied to assess ventilation within the study and surrounding areas. Since velocity ratio generated by wind pressure ventilation will be the main concern during the simulation process, this simulation was performed in an isothermal condition.

The diagram below **(Figure 6)** displays the mesh cells that are generated to perform precise simulation. This mesh topology was generated with enough details involving mesh cells including surrounding area and study area.

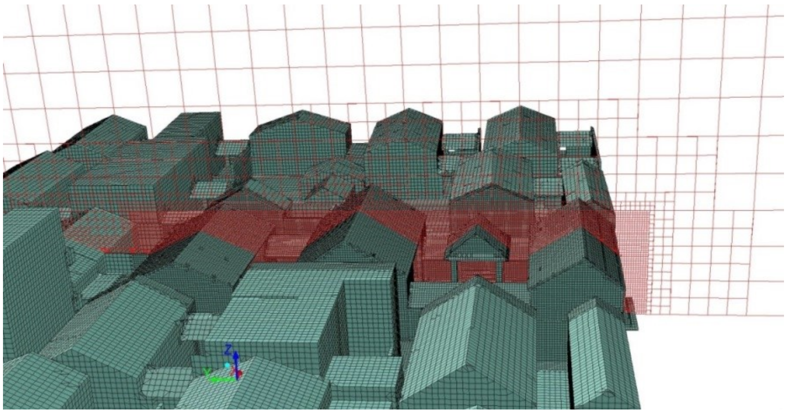


Figure 6. Diagram showing the mesh cells in vertical plane

For the air ventilation assessment of Youlan Ancestral Temple and its surrounding areas, test points (1m center to center along the axis aligned with north to south direction) are scattered at the patios, corridors and halls within the Temple. Meanwhile, test points are also assigned at cold alley along the Temple as well as the open space in front of the Temple.

3. RESULTS AND DISCUSSION

3.1 Contour of wind velocity in the prevailing wind direction

A plane at pedestrian level (2m level) is configured in the simulation model in the tested direction (SE). As can be seen from **Figure 7**: (a) For the surroundings of the Temple, higher values of velocity ratio mostly ranging from 1.05m/s to 3m/s （marked from light blue to red color） is displayed at the southern open space; (b) velocity ratio in the cold alley shows lower values mostly ranging from 0.15m/s to 1.05m/s, while that of southern entry of cold alley show rapid increase to values ranging mostly from 1.5m/s to 3m/s (marked by light green to red) which is due to the generation of channel effect as air flow through the entry; (c) for the Ancestral Temple, higher velocity ranging mostly from 1.35m/s to 2.4m/s (marked by light green to light orange) is recorded at the southern entrance and velocity ratios in the front patio are mostly ranging from 0.15m/s to 1.35m/s; and (d) VR in other parts of the Temple including halls, corridors aligned with north to east direction and the back patio display values lower than 0.15m/s, only that of area near the easterly doorway at back patio shows slightly increase.

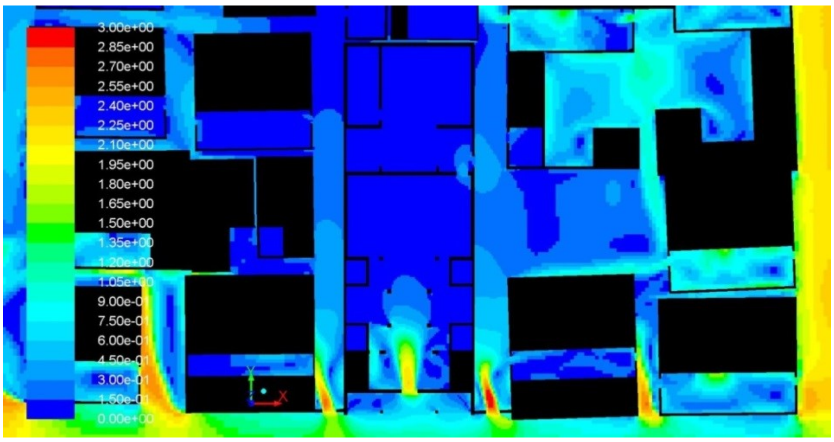


Figure 7. Contour of wind velocity in the wind direction of 157.5 degree at 2m level

To have a more visualize demonstration, velocity ratios of the test points along central axis of the Temple can be seen in **Figure 8**

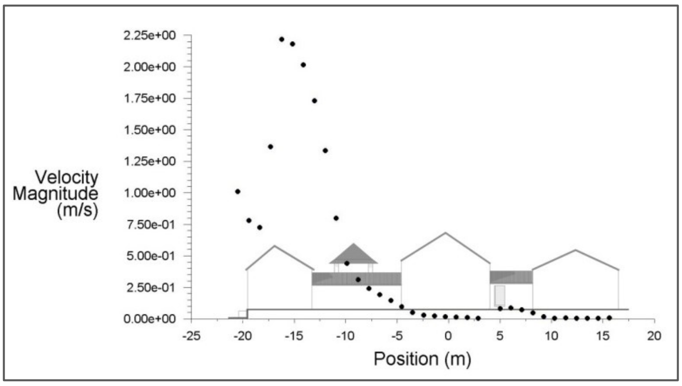


Figure 8. Contour of wind velocity in the wind direction of 157.5 degree at 2m level

3.2 Vector of velocity in the prevailing wind direction

Diagrams showing vector of velocity at 2m are displayed from Figure 9: (a) due to the overall layout approximately aligned with the prevailing wind direction, air flow through the cold alley fluently except at the southern doorway of 2m level, turbulence has been generated owing to the channel effect at the doorway; (b) air flow through the front gate and front patio orderly, however, vortex is revealed at the inner side of front gate; (c) for the back patio, air with low velocity ratios (mostly lower than 0.4m/s) flows from doorway to patio, which also slightly helps cool air generated from the alleyway flow into the back patio.

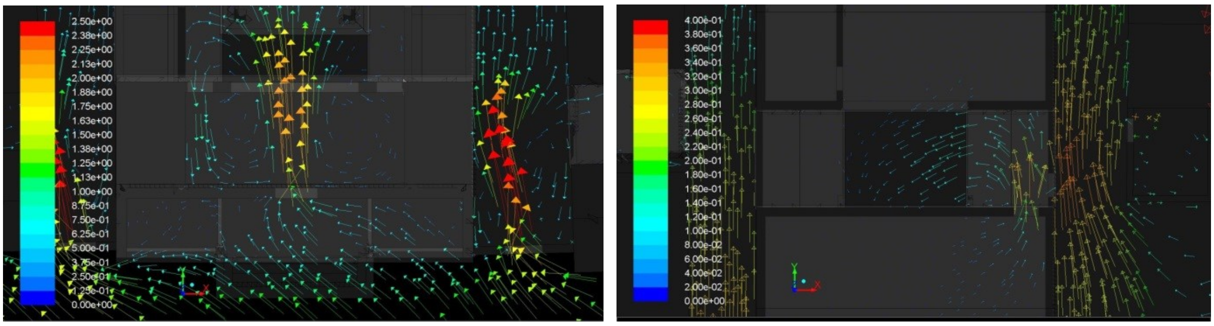


Figure 9. Vector of velocity in the wind direction of 157.5 degree at 2m level of front patio and back patio

To have more details of the ventilation at the patio as well as testifying previous research regarding to the inventory of patio in Lingnan Vernacular Dwellings, section planes aligned with central axis of the Temple are configured in the simulation model. As it is revealed from **Figure 10**: (a) when air flows through the upper area of back patio, only skimming flow is displayed during the simulation, which means barely no air flows into the patio directly; (b) velocity ratios below the eaves are mostly under 0.2m/s (*For showing distinctly difference, velocity ratios over than 0.18m/s are marked as red); (c) as air flows through the southern entrance into the front patio, velocity ratios decrease rapidly and create overall speed differences between the front patio and upper area of it, vector of velocity displayed in the diagram indicates that the air mostly goes up once enter the front patio.

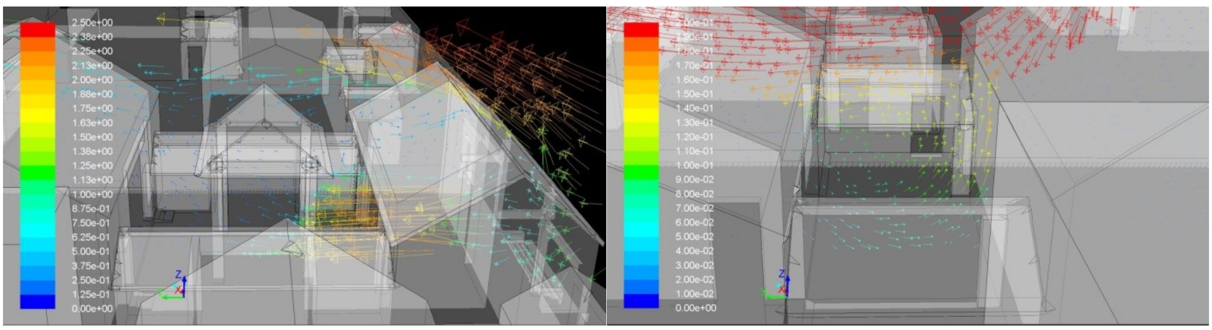


Figure 10. Vector of velocity in the wind direction of 157.5 degree (front patio and back patio)

4. FIELD MEASUREMENT FOR VALIDATION

To testify analysis result from the performance simulation and creating more comprehensive understanding of the ventilation mechanism, field measurement was conducted at 3p.m. on June 16th, 2014, relevant parameters including velocity ratio and air temperature is included. Square dots with English letters show where the parameters were measured. Meanwhile, every test point was measured twice with short interval during the field measurement in order to enhance reliability of data. Owing to the low velocity ratios in two halls during the field measurement, velocity ratio of test point F & I were not recorded.

To explore whether the result of field measurement shows consistency to performance simulation, decrease ratio of velocity at test point will be the indicator during comparison validation. Equation for the calculation of decrease ratio mentioned above is:

Decrease Ratio = (Velocity ratio at open space - Velocity ratio at test point)/ Velocity ratio at open space*100%

As can be seen from **Table 1**, most test points display consistency between field measurement and performance simulation, which displays that results extracted from the performance simulation in this study are reliable.

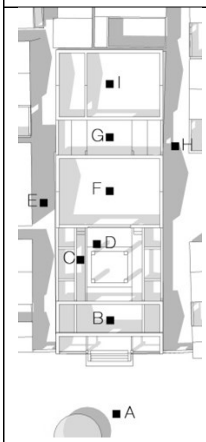
Overall Layout for Field Measurement	**Test point**	**Temperature(℃)**	**Velocity ratio(MPH)**	**Velocity ratio(m/s)**	**Decrease Ratio in field measurement**	**Decrease Ratio in CFD simulation**
	A	37.4	1.2	2.67	16%	13%
	B	36.3	1.0	2.23	92%	96%
	C	34.8	0.1	0.22	92%	92%
	D	35.0	0.1	0.22	75%	87%
	E	34.5	0.3	0.67	-	99%
	F	34.2	-	-	92%	97%
	G	34.8	0.1	0.22	67%	86%
	H	34.6	0.4	0.89	-	99%
	I	34.3	-	-		

Table 1. Velocity Ratio and air temperature of Test Points during field measurement

5. CONCLUSIONS

Basing on performance simulation and field measurement, quantitative analysis reveals more comprehensive understanding regarding to air ventilation especially for wind pressure ventilation of Lingnan Vernacular Dwellings. Some incomprehensive viewpoints including the relationship between velocity ratio of surrounding environment and that of within dwellings, the mechanism of wind pressure ventilation at the patios, and the importance of considering surrounding areas during performance simulation, are refined. Major findings can be concluded as below:

(a) Owing to the compact form of Lingnan Vernacular Dwellings, air seldom flows down into the patio directly during its flowing through the upper area of patios. Hence, previous research demonstrating that patios can work as air inlet under the circumstances of wind pressure ventilation is questionable;

(b) Restraining natural ventilation during daytime is one of the most significant strategies for insulation. The performed model displays significant differences from comparing velocity ratios in open spaces with that of cold alley, patios and interior. Higher air temperature (more than 2℃) being recorded in open spaces comparing with that of patios and interior during field measurement also support the finding mentioned above. Hence, common awareness that inducing natural ventilation into Lingnan Vernacular Dwellings so as to create better thermal comfort is incomprehensive;

(c) Wind pressure ventilation and thermal pressure ventilation may concur in the same direction when doors of Lingnan Vernacular Dwellings are opened along the cold alley. Hence, inventory regarding to the ventilation system combining cold alley and patio can be effective once taking experiences from this mechanism;

(d) Accuracy of performance simulation on vernacular dwellings will be increased if surrounding area is taken into consideration. For instance, if alleyway along the Temple is not built in the simulation model, higher velocity ratios of air which flows from the east elevation into the doorway will be recorded and lead to results with more residuals.

Basing on the findings concluded above, further extension of this study may be mentioned as following:

(a) As the mechanism of wind pressure ventilation usually induces velocity ratio mostly lower than 0.4m/s at the interior and patios, thermal pressure ventilation initiated by temperature differences between open space, cold alley, the patio as well as interior and how it works at night time in order to cool down the building will be the next step of this study.

(b) More comparison studies on other cases in Lingnan Region can be made by applying the methodology in this study in order to further summarize passive design strategies of Lingnan Vernacular Dwellings in a more scientific way.

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