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NATURAL VENTILATION CHARACTERISTICS OF COURTYARD BUILDINGS IN SINGAPORE

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ABSTRACT

Researches into natural ventilation characteristics of courtyard buildings have been carried out extensively in climates very different from tropical climate. Nevertheless, courtyards have been incorporated for centuries in traditional shop houses and also adopted in many modern commercial buildings in tropical countries such as Singapore. This paper discusses a study to investigate the natural ventilation characteristics of courtyard buildings in Singapore. Four typical courtyard buildings are examined. They include a three-storey shop house, a five-storey detached office building, a six-storey shopping mall and an eighteen-storey office building. Each of the 1:200 scaled models is investigated in wind tunnel to study the wind speed profile as well as the effects of various design parameters such as orientation of facade, location of courtyard etc. The measurements obtained from the wind tunnel are also compared with the actual full-scale measurements.

KEYWORDS
Tropical, natural ventilation, courtyard, wind tunnel, wind speed

INTRODUCTION

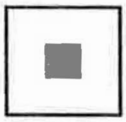
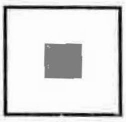
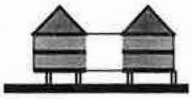
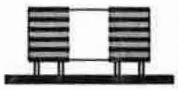
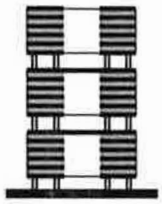
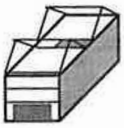
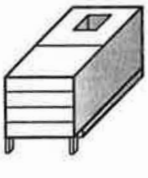
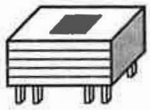
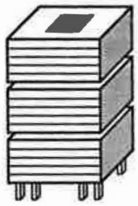
In the tropical places like Singapore with hot and humid ambient climate, the natural ventilation system has to be carefully incorporated in building design to meet an optimum and acceptable thermal comfort condition. There is a need to explore the natural ventilation characteristics of courtyard buildings in tropical climate since many courtyard ventilation researches have been conducted mainly for non-tropical climates such as hot-arid and temperate climate [Laouadi and Atif 1999]. It is believed that courtyards in tropical condition may have different characteristics due to its relatively high humidity, less fluctuated ambient temperature between day and night throughout the year and the absence of drastic climate change between dry and rainy season.

For more than a century, courtyards have been incorporated in tropical buildings such as in traditional Chinese shop houses and some of the colonial buildings [URA 1995]. Courtyards have been designed for two main purposes i.e. functional and spatial. The courtyard functions as fresh air intake for natural ventilation (air well) and also serves as daylight source (light well) for surrounding spaces. For spatial purposes, the courtyard lends interest to enchanting spatial experience by offering alternating naturally lit spaces and view to inner garden that is open to the sky [Saxon 1994].

COURTYARD BUILDING TOPOLOGY

The four building types being used for the wind tunnel tests represent the four common types of courtyard building in Singapore. The details of the buildings are shown in table 1.

TABLE 1
COURTYARD BUILDING TOPOLOGY

	MODEL 1 **Shop House**	**MODEL 2** **Office Building**	**MODEL 3** **Medium High-rise Mall Building**	**MODEL 4** **High-rise Office Building**
Urban Context				
Building Plan				
Schematic Section				
Isometric View				

METHODOLOGY

The prevailing wind direction during the site measurement in July-August 1999 was Southeast, therefore wind angle of 225° (Southeast) was used in wind tunnel testing. However, the dynamic fluctuation of hourly wind speeds on site cannot be simulated in the wind tunnel test. Therefore, four hourly data were chosen to represent the variation of hourly wind speeds. They are wind speeds of 2 m/s measured at 8.00 hours, 2.5 m/s at 11.00 hours, and 1.5 m/s at 15.00 hours, and 1 m/s at 18.00 hours.

Since courtyard is the main focus of this study, the thermistors were placed carefully in such a way to capture wind speeds in the courtyard's surrounding spaces. Before each test was carried out, all thermistors were tested to make sure that they would give the same range of sensitivity and responsive voltage output for reliable data acquisition. A PC-based data logger was used to collect and analyze the experimental data from individual thermistor up to 50 points simultaneously.

The boundary layer wind tunnel was first calibrated to replicate the power law coefficient of k = 0.35 and a = 0.25, which is the characteristic of built up urban area [Liddament 1996]. This coefficient applies to the full-scale measurement site and provides a good reference velocity profile for the comparative study.

RESULTS

Model 1: Shop House

The lowest wind speeds were found in the second storey, especially at the point near the rear wall due to lack of cross ventilation (Figure 1). On the other hand, the points between the front window and courtyard showed higher wind speeds because of cross ventilation that enhance the local wind speeds.

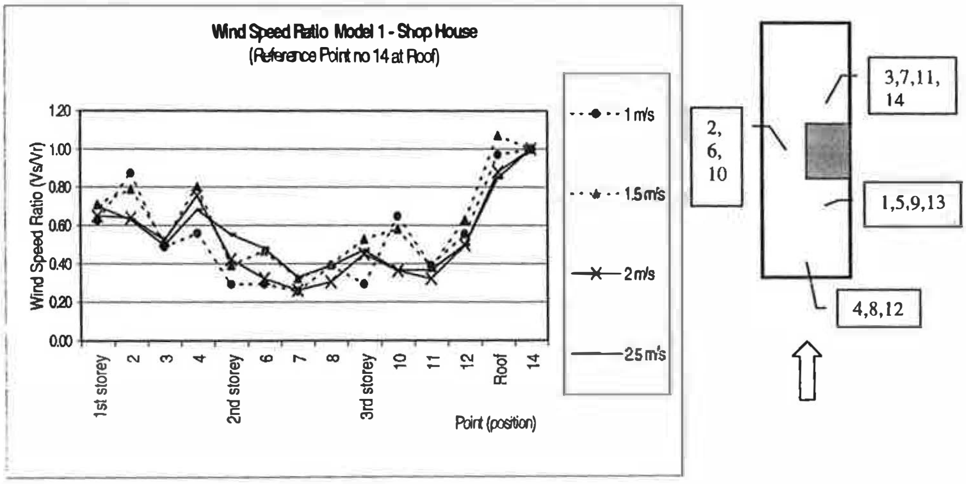


Figure 1: Wind speed ratio of Model 1 – Shop House

Model 2: Office Building

The lowest wind speed was found in third storey, which was approximately at mid height of the building. The wind speeds on the first storey were about 0.8 – 0.9 compared to the undisturbed wind speed on the roof. The average wind speed in third storey was in the range of 0.2 – 0.4 (see figure 2).

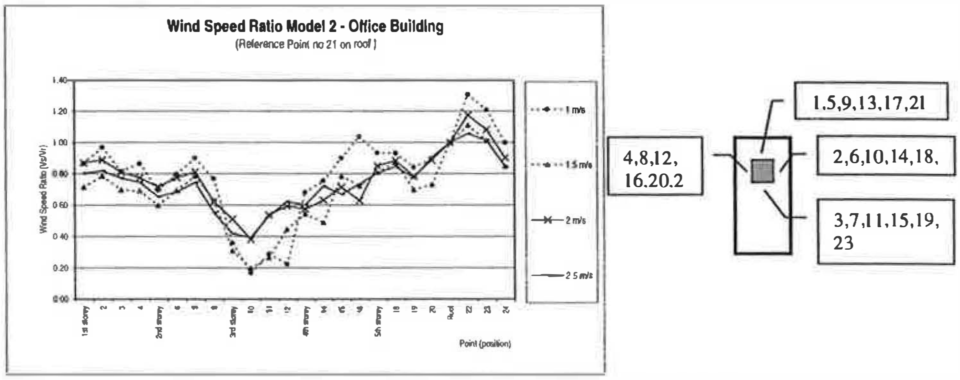


Figure 2: Wind speed ratio of Model 2 –Office Building

Model 3: Medium High Rise Building

The lowest wind speed occurred on the fourth storey with average wind speed ratio of approximately 0.4, while the ratio for sixth storey is about 0.8 (figure 3). For external wind of about 1 m/s, the fourth storey experienced relatively low wind speeds of 0.2 m/s.

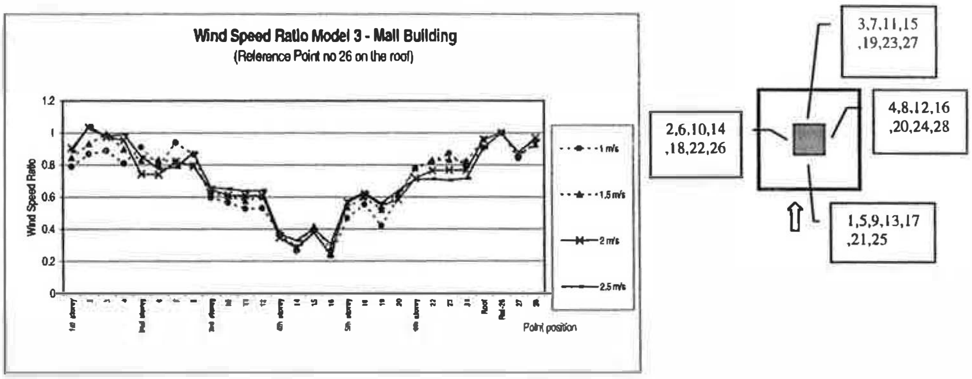


Figure 3: Wind speed ratio of Model 3 – Mall Building

Model 4: High Rise Building

Generally, there was a similar wind speed profile in each courtyard at the three different stacks. The minimum wind speeds were found in the middle storey on each stack (5th, 11th and 16th storey).

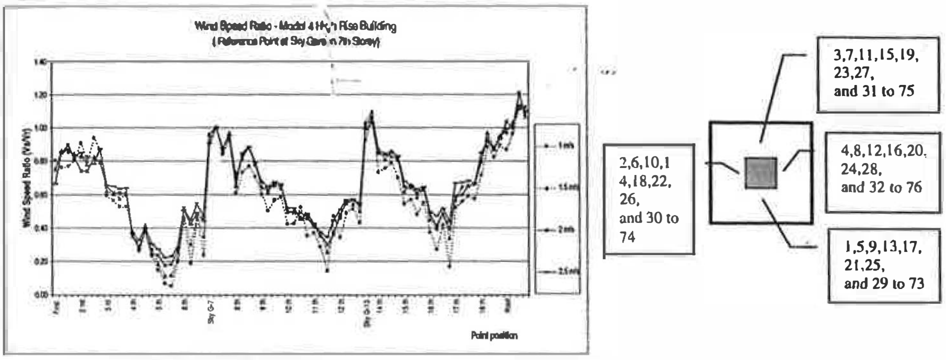


Figure 4: Wind speed ratio of Model 4 – High Rise Building

Comparison of Scale Model and Full Scale Measurement

By using point 9 on the roof as the reference wind speed, the comparison of wind speed ratio between full-scale measurement and wind tunnel was carried out for the Office building (Figure 5). The wind speeds from the wind tunnel test were found to be 20% higher than the full-scale measurement. Both measurements showed that the lowest wind speed ratio occurred at points 5 – 8. To have a better understanding on the results of these two methods, correlation coefficients between two corresponding wind speeds were calculated. The average correlation coefficient for four wind speeds is 0.7799. This observation is similar to a previous study, which showed that the wind tunnel test produced higher readings than those averaged over 1-10 minutes in the full-scale tests and the correlation coefficient was 0.8. [Kawamura 1988].

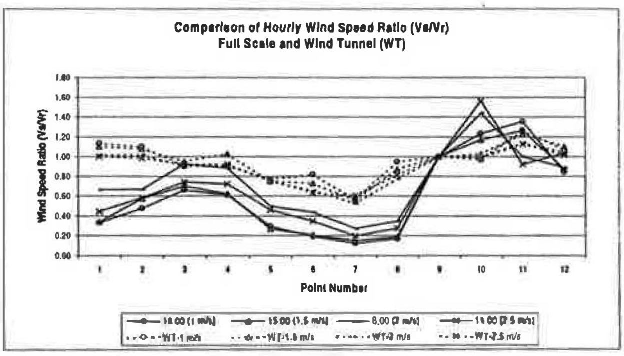


Figure 5: Comparison of wind speed ratio.

DISCUSSION

Ventilation Performance of the Four Courtyard-buildings

From figures 1 to 4, it can be observed that the highest wind speeds (1.25 to 1.8 m/s) tend to occur mainly at first storey with lowest wind speeds (0.4 to 0.6 m/s) in the middle of the buildings. Thus, the incorporation of such courtyard should be ideal for buildings where activities are to be carried out at first storey such as for open theatre, exhibition etc.

Orientation of Facade Opening

The study showed that the orientation of opening in the facade with respect to wind direction critically affect the natural ventilation of the buildings. For example in Model 1, highest interior wind speed occurs when wind is perpendicular to the front façade. For Model 2, this occurs when the wind is perpendicular to either the front or back facade. For Models 3 and 4, since they have symmetrical facades on all directions with courtyard at the centre, the wind speed is affected mainly by the surrounding obstructions. However, for model 4, it is interesting to note that the wind speed profile was similar in the three stacks and the lowest wind speeds occur in the middle of each stack.

Position of Courtyard

For Model 1, the wind speed ratios showed lower value (0.2-0.4) in the spaces near the rear wall because of the "dead end" space. Places between the courtyard and front windows showed higher ratios (0.45-0.8) due to the enhancement by cross ventilation. For Model 2, due to asymmetric courtyard position, the distances (section width) from courtyard to front and rear façade are different. Thus, the space with narrower section width experienced higher wind speeds due to better cross ventilation. For Models 3 and 4, by having the courtyard in the centre, the wind direction and configurations of the surrounding buildings become the determinant factors in governing the wind speeds.

CONCLUSION

This study shows the potentials of using courtyard to enhance the performance of naturally ventilated buildings, by strategically placing the courtyard in the most suitable location as well as orientating the facade opening in the prevailing wind direction. Nevertheless, courtyard is only one of the available design strategies in naturally ventilation. Therefore, a courtyard can not be solely relied upon to achieve a good ventilation performance without any further consideration and decision on other potential design parameters such as the floor-to-floor height ratio, depth of building plan, types of window, roof shape etc.

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