Influence of building design on thermal comfort of hawker centers in Singapore

Song Jiafang and Wong Nyuk Hien

Department of Building, School of Design and Environment, University of Singapore, Singapore

ABSTRACT: This study was conducted using field study and wind tunnel experiment. Field study on one typical hawker center was adopted to evaluate directly the thermal comfort conditions and to capture the building design elements which are likely to affect the thermal comfort in the actual environmental context. The field study included long-term micrometeorological measurement and short-term questionnaire survey. The long-term micrometeorological measurement recorded microclimate data including dry bulb temperature, wind speed and direction, relative humidity and solar radiation etc. The short-term questionnaire survey covered both the objective measurements and the subjective evaluations, which were conducted simultaneously. The objective measurements involve air temperature, relative humidity, wind speed and globe temperature for semi-outdoor spaces. Wind tunnel experiment was carried out to stimulate wind effects on hawker centers, which included influence of wind on natural ventilation performance. The study explored the impacts of building design such as roof type, stall height and stall gap on the natural ventilation of hawker centers.

Keywords: thermal comfort, building design, hawker centers, wind tunnel, natural ventilation

1. INTRODUCTION

Although it is very common that air-conditioners are utilized in both residential and commercial buildings in hot-humid countries such as Singapore, where high day time temperatures and relative humidity are commonly experienced over the greater part of each day, some building types, such as hawker centers, rely on natural ventilation to achieve comfort conditions. The provision for indoor thermal comfort is among the most important objectives in the design and construction of non-air conditioned buildings to satisfy the high expectation of the living standards of the people. This is particularly important in the design of the hawker centers, as they are known locally, which is a significant feature of life in the equatorial island as it provides affordable food for Singaporeans.

Hawker centers, located conveniently around the whole island of Singapore, are the main dining places in which they provide most Singaporeans with economical meals. Various food and beverages are offered by numerous private merchants in the stalls. Purchasers buy these and consume these at tables displayed around the center and in the couloirs. The space where food and beverages are consumed is roofed but without walls, to ensure natural ventilation. There are currently approximate 139 hawker centers around the island [1]. Generally, there are various hawker centers in Singapore in terms of architectural design. Architecturally, most hawker centers are fairly large one-storey structures with a typical floor area of about 2000 m^2 and roof height of about 5m. Walls are not constructed in order to allow maximum cross-ventilation. The most common shape of the hawker center is that of a rectangle which has a larger length to width ratios but covering approximately the same area.

The objectives of this study are as follows:

1. To study the thermal comfort condition of a typical hawker center in Singapore.
2. To find out the microclimate impact on the thermal conditions of the hawker center.
3. To investigate the design parameters which govern the natural wind movement inside the hawker center.

2. METHODOLOGY

2.1 Overview of the methodology

This study was conducted using field study and wind tunnel experiment. Field study on one typically actual hawker center was adopted to evaluate directly the thermal comfort and to capture the building design elements which are likely to affect the thermal comfort in their actual environmental context. Wind tunnel experiment was carried out to stimulate wind effects on hawker centers, which included influence of wind on natural ventilation performance.

2.2 Field study

In this study, the field study included long-term micrometeorological measurement and short-term questionnaire survey. The long-term micrometeorological measurement recorded microclimate data including dry bulb temperature, wind speed and direction, relative humidity and solar radiation etc. The long-term measurement was utilized weather station which was installed an open space without shading outside the hawker center under study. Figure 1 shows the installation of the weather station.

Figure 1: Installation of the weather station for long-term measurement outside the hawker center.

The short-term questionnaire survey covered both the objective measurements and the subjective evaluations, which were conducted simultaneously. The objective measurements involve air temperature, relative humidity, wind speed and globe temperature for semi-outdoor spaces [2]. The thermal comfort survey will be carried out with an interview with people in the hawker center. In order to ensure that the thermal comfort perception of the respondents would not be affected by the type of food they consumed, the interview was performed usually before the respondents took their food. The site was divided into three sections because during the site walk-through, it was found that three sections might have different thermal environments. Figure 2 shows the plan view of the hawker center. The data collection was carried out at two separate time periods; from 11:30am to 1:30pm and 4:30pm to 6:30pm. Measurement of the two physical parameters, metabolic rate and clo value, were also recorded. For the subjective evaluations, the seven points ASHRAE thermal sensation scale as well as the Bedford thermal comfort scale were used. Other scales to gauge the perception of humidity, air movement and air freshness were also employed.

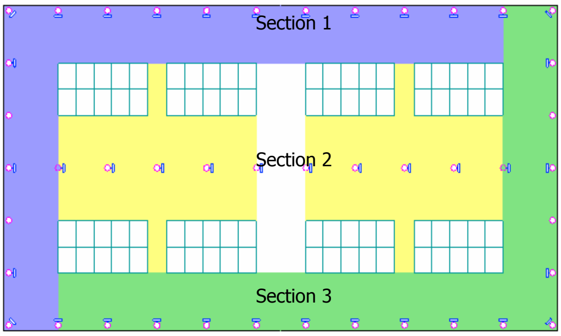


Figure 2: Plan view of the hawker center surveyed.

2.3 Wind tunnel testing

2.3.1 Description of the wind tunnel testing process

In this study, the wind tunnel experiment is performed at the Wind Tunnel Laboratory in National University of Singapore (NUS). The Wind Tunnel Laboratory has an atmospheric boundary layer wind tunnel of dimension 1.75 m high, 3.75 m wide and 17.00 m long. A 1:100 scale model of the hawker center were established (See Figure 3).

Figure 3: Model of the hawker center tested in the wind tunnel.

In this experiment, the Dantec airflow measurement system was used for measurements of the wind speed in the building model. There are altogether 20 anemometers/sensors in this system. The anemometers were connected to a data logger, which logged the wind speeds at each channel continuously until the readings were stable. Figure 4 shows the locations of the 20 sensors placed in equal numbers in the four rows. The magnitude of the wind speed set for each direction was based on the weather data from the Singapore meteorological station over 18 years (See Table 1) [1]. However, the raw data from the meteorological station could not be used directly as these mean wind speeds were recorded by instruments situated at 10m above ground. To simulate the wind condition of the hawker center, the mean wind speed from each direction were corrected using the power law.

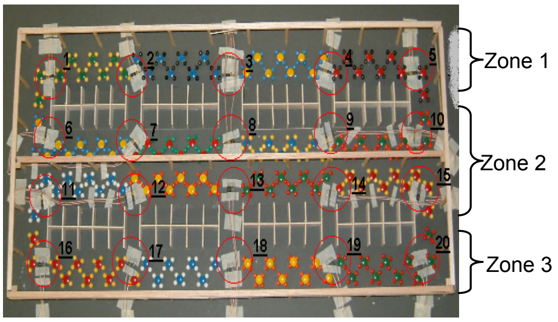


Figure 4: Placement of the 20 sensors in the model.

Table 1: Wind direction and mean speed for 18 years

North	4.15m/s	South	5.81 m/s
Northeast	6.02 m/s	Southwest	4.77 m/s
East	6.22 m/s	West	3.73 m/s
Southeast	6.64m/s	Northwest	2.90 m/s

In order to calculate the average wind speed at each sensor point taking into account the wind speed from all the eight directions, the wind speed at each direction was weighted by the percentage frequency distribution of the respective wind direction (see Table 2).

Table 2: Average percentage frequency of wind direction in Singapore 1987-1997

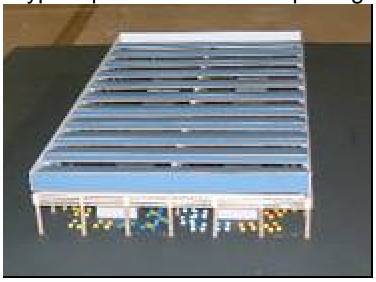
	SW	W	NW	N
Ave %	5.94	7.25	10.29	21.06
	NE	E	SE	S
Ave %	15.52	6.90	15.19	17.84

2.3.2 Design parameters investigated in wind tunnel experiment

2.3.2.1 Roof type

There are three kinds of roof designs introduced for wind tunnel testing (see Figure 5). Roof type 1 is named as pitch roof without opening. It was designed and constructed with overall dimensions of 70.4 m length x 34.4 m width x 11.6 m height with a roof angle of 16°. There are louvers under the eaves in which they are functioned as shading devices.

Type1: pitch roof without opening



Type2: flat roof with angle of inclination

Type 3: pitched roof with openings

Figure 5: Models with different type of roofs.

Roof type 2 is designated as flat roof. It has overall size of 70.4 m length x 34.4 m width x 11.6 m height. The roof is made of steel and is divided into several pieces of metal sheeting with angle of inclination approximately 45° in order to promote ventilation. The size for each piece of steel sheeting is around 34.4 m length x 6.00 m width.

Roof type 3 was designed as a pitched roof with openings. This is the current type of roof used in the food centre. It has overall size of 70.4 m length x 34.5 m width x 11.5 m height at roof angle of 22°. Six smaller openings are constructed at the roof slope while another two equally large openings located at the end sided of the roof. Both the smaller and larger openings are designed in triangle shapes having the sizes of 14.23 m base x 3.32 m height and 70.4 m base x 6.08 m height respectively.

2.3.2.2 Stall height

Stall height is another parameter to be tested to see if it has any effect on natural ventilation performance in the food centre. Stall heights of 2.0m as base case, 2.5m and 3.0m were modelled to examine the effect of the increment of the stall gap as shown in Figure 6. As can be seen from previous diagram (Figure 5), the stalls were laid in 2 rows whereby each row consists of 40 numbers of stalls. Each size of stall is about 2.5 m length x 2.5 m width.

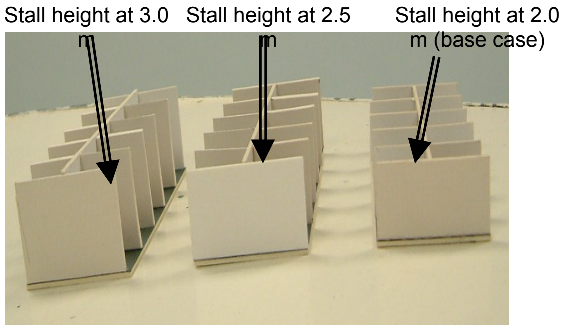


Figure 6: The picture of the different stall height.

2.3.2.3 Stall gap

Four sets of stall gaps were tested to examine its effect to the ventilation condition in the hawker centre. Based on the base case, the stall gaps were made an increase of 0.5m, 1.0m and 1.5m and 2.0m respectively (See Figure 7).

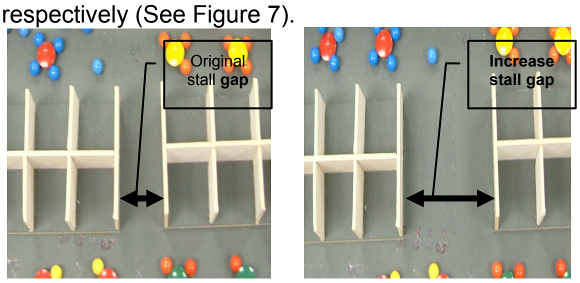


Figure 7: Pictures of the stall gap increase.

3. DATA ANALYSIS

3.1 Field study on thermal comfort

3.1.1 Objective measurements

Figure 8 shows the inside and outside air temperature of the hawker center. It can be seen that inside air temperature is more fluctuated than outside air temperature. It is due to the fact that too much factors can affect the inside air temperature, such as heat gave out by cooking, numbers of people eating etc. During noon time, it is apparent that inside air temperature is lower than outside temperature. The reason for this is that the building elements of the hawker center such as roof, louver can prevent intense solar radiation at noon. It indicates that shading devices for tropic building is an effective method to prevent the solar radiation.

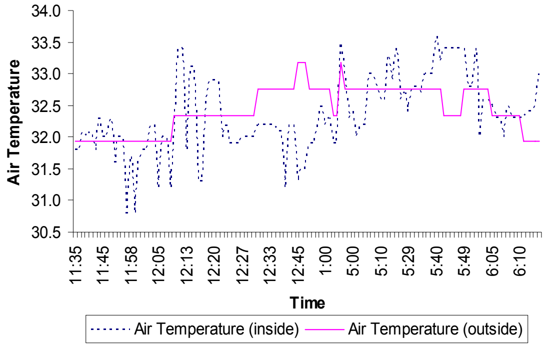


Figure 8: Comparison of inside and outside air temperature of the hawker center

Figure 9 shows the inside and outside relative humidity of the hawker center. It is found that inside relative humidity is much higher than outside relative humidity. More water vapor produced by cooking resulted in high humidity. It implies that it is of consideration that utilizing effective building design methods improves natural ventilation of the hawker center to effuse the water vapor outside in order to decrease the humidity inside.

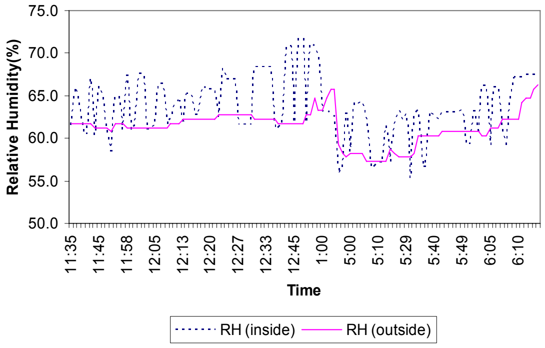


Figure 9: Comparison of inside and outside relative humidity of the hawker center

3.1.2 Subjective evaluations

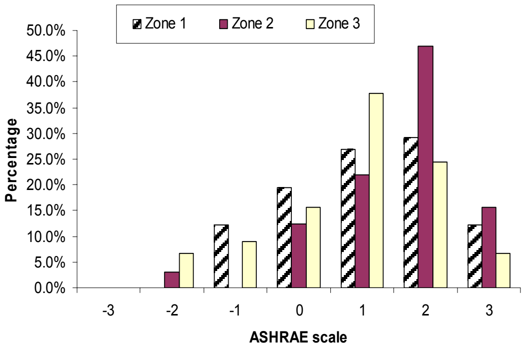


Figure 10: Vote distribution on thermal perception based on the ASHRAE scale

Figure 10 shows the vote distribution on thermal perception based on ASHRAE scale. It indicates that thermal sensation votes are skewed to right toward the scale to feel warm. Most votes are found in the right categories (+1, +2). It implies that the thermal conditions in the hawker center are not good. Zone 2 is the worst section among the zones. The reason for this is that Zone 2 is located in centre of the hawker center, whereby chances of exposing to the large amount of outdoor air are relatively small.

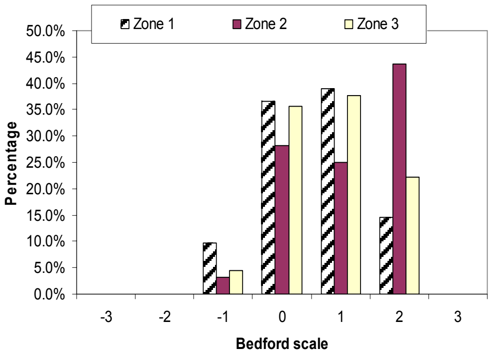


Figure 11: Vote distribution on thermal perception based on Bedford scale

Figure 11 shows the vote distribution on thermal perception based on Bedford scale. Most thermal comfort votes for Zone 2 and Zone 3 are found in the central categories (-1, 0, +1). Based on the vote distribution, Zone 1 is the most satisfied zone, and Zone 2 is the most unsatisfied zone. From the results of subjective evaluations, it is concluded that the thermal condition of Zone 2 is the worst. This result is consistent with the previous result of the ASHRAE scale.

3.2 Results from wind tunnel experiments

3.2.1 Roof type

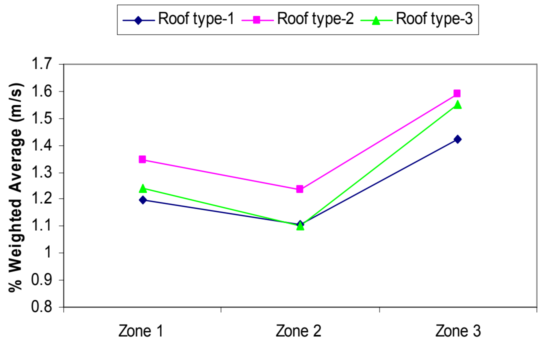


Figure 12: Comparison of the overall percentage weighted average wind speed of each zone for the different roof types

Figure 12 shows the comparison of the overall percentage weighted average wind speed of each zone for the different roof types. From the results, it can be seen that roof type-3, which is pitch roof with openings at the slope has the worst ventilation performance. And roof type-2 has the best in the ventilation performance. The reason for this is probably that the wind tends to channel vertically upwards and exit through the roof openings at the slope, which is due to the negative pressure built up at surface of the low pitch roof (<= 22º). Suction flow is produced through the openings at the slope surface. Hence, the wind would channel vertically outwards via the openings instead of moving to the floor level. The results indicate that roof type-2, which is the flat roof with metal sheeting tilted at gradient of 45° has the best ventilation performance. It is due to the fact that the positive pressure was caused by the gradient of the metal sheeting (>22º). The positive pressure would force the external wind to channel downwards and travel onto the ground level (See Figure 13) . Thus, the metal sheeting of the roof has functioned as airflow inlet that induced wind to flow into the inner space.

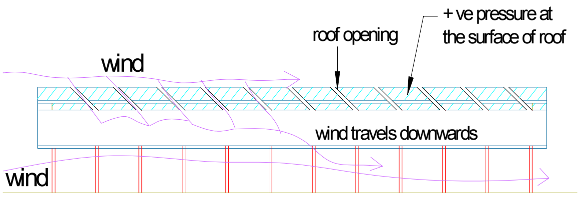


Figure 13: Sectional view of Roof type-2 which shows the distribution of wind into the inner space through the roof openings

3.2.2 Stall height

Figure 14 shows the comparison of the overall percentage-weighted average wind speed of each zone with increment of stall height. The results show that the ventilation performance is inversed proportional to the raise in the stall height. The percentage drop in the wind speed is due to the height of stall partitions that becomes the barrier for the wind to flow through. The stall partitions that are positioned perpendicular to the prevailing wind block the wind from flowing into the inner spaces. Besides, they also hindered the possibility of cross-ventilation effect across the passageway and thus the ventilation was reduced tremendously.

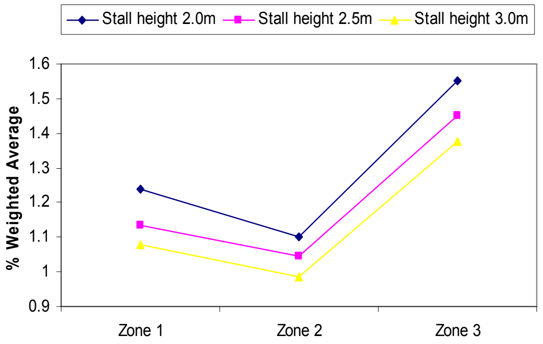


Figure 14: Comparison of the overall percentage-weighted average wind speed of each zone with increment of stall height

3.2.3 Stall gap

Figure 15 shows the comparison of the overall percentage-weighted average wind speed of each zone with increment of stall gap. From the results, it indicates that there is no consistent tendency in terms of the increment of stall gap. It implies that only increment of the stall gap is not an effective design method.

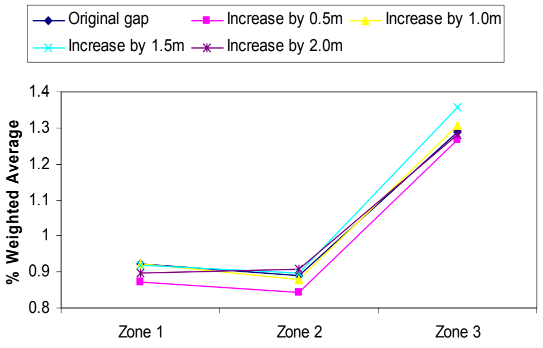


Figure 15: Comparison of the overall percentage-weighted average wind speed of each zone with increment of stall gap

4. CONCLUSION

This study illustrates the use of field study and wind tunnel experiment to investigate the influence of building design on thermal comfort in a typical hawker center in Singapore. By carrying out a field study to measure the thermal comfort conditions of the hawker center, the microclimate impact on the thermal conditions of the hawker center was find out. Wind tunnel tests were carried out to determine the impact of some building design elements on the natural ventilation performance. The results shows that the flat roof with metal sheeting tilted at gradient of 45° has the best ventilation performance. In order to achieve better natural ventilation performance, it is suggested to keep the stall partitions as low as possible so that obstruction of the airflow is minimized.

REFERENCES

[1] HDB, Annual report. (1999/2000).
[2] ASHRAE. Chapter 8 – Physiological Principles and Thermal Comfort. In Handbook of Fundamentals. Atlanta: American Society of Heating, Refrigerating and Air- Conditioning Engineers, Inc.,(2001), 8.1-29.
[3] Singapore Meteorological Services (SMS). Annual report on Singapore Weather, Singapore; SMS Office. (1995).