August 2010 • DES 80 (Edited 21.11.2018)
This note was reviewed and approved for currency in November 2018

ENVIRONMENT DESIGN GUIDE

THE IMPACT OF VERANDA ON A SINGLE-SIDED NATURALLY VENTILATED BUILDING

M F Mohamed, D Prasad, S King

This paper investigates the impact of veranda on the indoor and outdoor airflows of a single-storey building with various opening configurations. Focussing on a wind-driven single-sided ventilation strategy, the investigation suggests that the provision of veranda with a correct combination of openings can improve indoor air flow in single-sided naturally ventilated building. On the other hand, inappropriate veranda configuration together with an incorrect combination of openings can significantly reduce indoor ventilation performance.

Keywords:
indoor air quality, natural ventilation, veranda, airflow

Figure 1: A simple form of veranda located at studio units

(Image: Mohamed, Prasad and King, 2010)

1.0 INTRODUCTION

Single-sided ventilated buildings have been assumed to be inefficient in terms of utilising natural ventilation compared to cross-ventilated buildings. However the ventilation performance of single-sided building can be improved to achieve acceptable indoor air flow by adopting appropriate facade relief, for example, by incorporating a veranda. Currently, the only available research investigating the relationship between veranda and indoor airflow for single-sided ventilated buildings is Givoni (1968), which remains seminal.

This paper presents a pilot study for investigating the effects of veranda on a single-sided ventilated multi-storey building. The paper focuses on the effect that incorporating veranda as a facade relief has for indoor air velocity and age of air.

2.0 VENTILATION

Ventilation is defined as 'the process by which "clean" air (normally outdoor air) is intentionally provided to a space and stale air is removed' (Liddament 1996). The purpose of ventilation is to provide an acceptable microclimate that provides good indoor air quality and thermal comfort for occupants of the building (Awbi 1991, Allard 1998). Thus ventilation, which affects air velocity and air change rate, plays an important role in building design.

Natural ventilation for buildings can be divided into two distinct categories: wind driven and buoyancy driven. This study is only concerned with the wind-induced ventilation that influences the outdoor and indoor airflows where temperature difference is not a factor. The study is limited to single-sided ventilation where one or more openings exist only at one external wall of a closed room. Its counterpart, cross ventilation (a condition where openings exist in two or more external walls), is not discussed in this study since it is well accepted to be a better option for ventilation. Cross ventilation is also preferred to single-sided ventilation by the authorities: for example, the Building Sustainability Index (BASIX) tool of the New South Wales government gives no point to single-sided ventilation, while a point is given to cross ventilation without looking into the ventilation efficiency of the building.

Despite common understanding that it provides less efficient natural ventilation than cross ventilation, single-sided ventilation has been widely used in buildings due to various factors such as land and cost constraints and the need for space efficiency.

3.0 VERANDA AS AN ELEMENT TO INDUCE INDOOR AIR FLOW

A veranda is defined as 'an open gallery or balcony with a roof supported by light, usually metal, support' (Fleming et al. 1991). There are similarities between the definitions of veranda and balcony, where balcony is defined as 'a platform projecting either from an inside or an outside wall of a building' (Cowan and Smith 2004).

Veranda and balcony have similar characteristics which can improve indoor air flow by acting as a transitional space between the outdoor and indoor environment. In this exercise, a veranda and balcony are accepted to be similar.

A veranda is an important architectural element in various climates, especially tropical and hot climates (Oktay 2002, Yuan 1987). In Malaysia, for example, the veranda is a significant architecture element in vernacular architecture such as the traditional Malay house. In New South Wales, according to local law, it is compulsory to provide a 2.0 m minimum depth dimension of balcony to an apartment unit when private space is not provided (Department of Infrastructure Planning and Natural Resources, 2002). Due to the large number of buildings that have incorporated veranda as their facade relief, therefore, it is useful to understand the impact of veranda on the indoor air quality of single sided ventilated building.

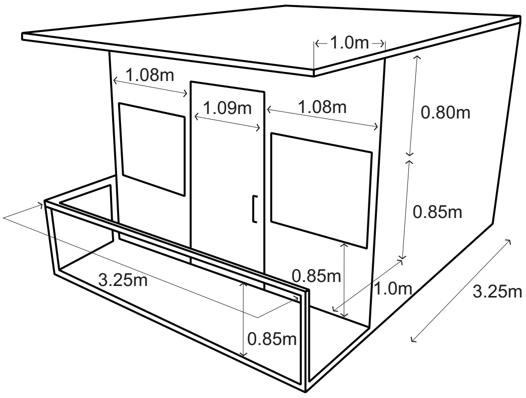

Figure 2: The real-scale computer-generated image of Case 7 model (See Figure 3) with 100 per cent porosity balustrade, 1.0 m width veranda and two sliding windows (1.08 m x 0.85 m each) with 50 per cent porosity

(Image: Mohamed, Prasad and King, 2010)

In addition to its potential to achieve thermal comfort through the improvement of indoor ventilation performance, the veranda has environmental, social and economic benefits (Mohamed et al. 2008).

According to Chand et al. (1998), the provision of balconies in buildings can contribute towards improving indoor air flow. However that study only investigated the pressure distribution on building surface as the result of provision of balconies at the facade. It did not specifically investigate the indoor air flow resulting from adopting balconies.

Prianto and Depecker (2003, 2002) suggest that in designing dwellings, especially in humid tropical regions, proper considerations should be given to the design and configuration of balconies and openings, as they play an important role in inducing indoor natural ventilation. However improvement of indoor natural ventilation is dependent on various factors. According to Larsen and Heiselberg (2008), the amount of air passing through an opening is influenced by the wind speed, inside and outside temperatures, wind direction, turbulence characteristics, pressure variations, as well as the size, type and location of openings.

The provision of veranda on a facade of a building can create variations to the pressure distribution on the facade. Thus, the pressure variations created by the veranda can be used to improve indoor air flow by providing appropriate openings. By positioning one opening at a high wind-pressure area and another opening at a lower wind-pressure area, a wider pressure difference is created and consequently forces the indoor air to move faster.

The size of the opening also has an influence on ventilation performance. In single-sided buildings with a single opening, the indoor ventilation rate and average indoor air speed are very dependent on the opening size. Generally, a larger opening size provides better ventilation performance. The location of openings can also affect indoor air velocity. Allard (1998) recommends more than one opening in single-sided ventilation situations, which should be placed far apart to make better use of skewed winds.

To optimise the benefit of veranda in inducing indoor air flow, it is necessary to perform a thorough study on the configurations of veranda and building as well as its contextual parameters. Such a study can be performed by experimental analyses such as using a wind tunnel, or numerical and computer simulations. For the purpose of this paper, a computer simulation was completed to study the impact of veranda on the outdoor and indoor air flow of a one-storey building and the relationship between veranda and openings.

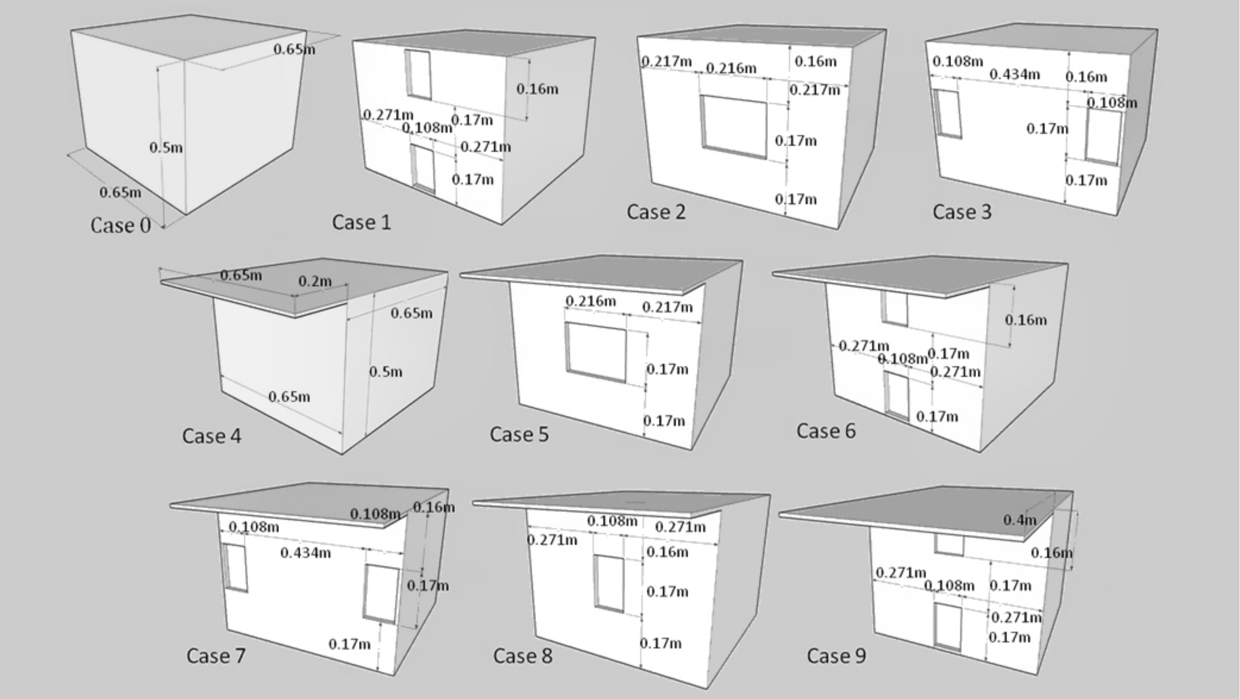

Figure 3: Room models for Cases 0 to 9 as simulated (reduced to 1:5 scale)

(Image: Mohamed, Prasad and King 2010)

4.0 COMPUTATIONAL FLUID DYNAMICS

There are various methods to investigate indoor and outdoor air-flow characteristics. They are the full-scale experiment method, the scaled-model wind tunnel experiment and computational fluid dynamics (CFD). Among all the methods outlined, CFD is selected for this study for various reasons: it does not require physical modelling; it is cost and time efficient; and, most importantly, it provides reliable results. Building simulation is well established and is able to deal with complexity of scale and diversity of component interactions; thus it has gained a respected role in the prediction, assessment and verification of building behaviour (Malkawi and Augenbroe 2003).

4.1 Simulation

Airpak 3.0 software was used for the study. It uses the FLUENT CFD solver engine for thermal and fluid-flow calculations. Airpak is an accurate, quick and easy-to-use design tool that simplifies the application of airflow modelling to the design and analysis of ventilation systems (Fluent Inc 2007).

The basic dimension of the models selected for this study, an external wind speed of 1.25 m/s (metres per second) and standard two equation k-ε turbulence model, are similar to the simulation completed by Mak et al. (2007), which is used as a reference. Besides that, works by Givoni (1976) are also used for reference purposes. The works by Mak and Givoni are used as references to ensure that the results achieved by this computer simulation study are within an acceptable range. Since this is a pilot study, only one wind speed and wind direction is selected. The wind speed is 1.25 m/s, while the wind direction is perpendicular to the front facade of the room models. The simulations are conducted in isothermal condition, thus temperature does not influence the airflow characteristics.

Ten room models with a reduced scale of 1:5 were simulated for this study. The scaled dimension is similar to Mak's work and Givoni's scaled model testing using a wind tunnel. According to Givoni, scaled model testing is possible since scaled model testing provides similar flow patterns in comparison to full-scale body. The dimensions of full-scale model and simulated room models are shown in Figure 2 and Figure 3, respectively.

It is important to note that the protruding element in the models indicates the provision of balcony. The balustrade is not included in the simulation models due to its 100 per cent porosity, with an assumption that it has very little affect on the airflow. The width selected for the veranda is 1.0 m, as it is approximately the minimum practical width suitable for human occupation. The opening used for the simulation is a sliding window with 50 per cent porosity, thus the uninterrupted opening in the simulation is half of the size of a sliding window.

Case 3 is similar to the works by Mak and Givoni, whereas Case 2 is similar only to the work by Givoni. Other models are variations of Case 0, in which they vary in term of provisions of protruding element and different arrangement, number and size of openings. The room size for each case is the same: 0.65m wide x 0.65m deep x 0.5m high. The following (Table 1) is the description of each case.

CASE	SPECIFICATIONS
0	No opening and no horizontal projection
1	Two vertically arranged openings (0.108m x 0.17m) with no horizontal projection
2	One opening (0.216m x 0.17m) with no horizontal projection
3	Two horizontally arranged openings (0.108m x 0.17m) with no horizontal projection
4	No opening but with a 0.2 m horizontal projection
5	One opening (0.216m x 0.17m) with a 0.2 m horizontal projection
6	Two vertically arranged openings (0.108m x 0.17m) with a 0.2 m horizontal projection
7	Two horizontally arranged openings (0.108m x 0.17m) with a 0.2 m horizontal projection
8	One opening (0.108m x 0.17m) with a 0.2 m horizontal projection
9	Two vertically arranged openings (0.108m x 0.17m) with a 0.4 m horizontal projection

Table 1: Description of room models

4.2 Analysis of Results

Assessing CFD results requires a validation process, which is normally completed by comparing the results to existing experimental data. In this study, the percentages of mean indoor air speed to wind speed at an angle perpendicular to the facade obtained from the CFD simulations are compared with the results from Mak and Givoni.

Case 3 indicates that the percentage of mean indoor air speed is 3.84 per cent, which is approximately similar to the result found by Mak, however it is lower than the result found by Givoni, which is 6.5 per cent. Case 2 shows that the percentage of mean indoor air speed to wind speed is 2.88 per cent, which is lower than the 4.7 per cent found by Givoni. As explained by Mak, the differences between the results in a CFD simulation and a wind tunnel test as run by Givoni are the result of the method adopted for indoor wind speed measurement. In Givoni's work, wind speed measurement was limited to five selected measurement points, whereas in CFD simulation mean indoor air speed is obtained by calculating at every point of indoor space, including point with 0 m/s air speed. Thus, having an approximately similar result to Mak and a lower percentage than Givoni, as expected, show that the results are within a reasonable range. Therefore, the results obtained from CFD simulations are considered to be acceptable to fulfil the objective of this study.

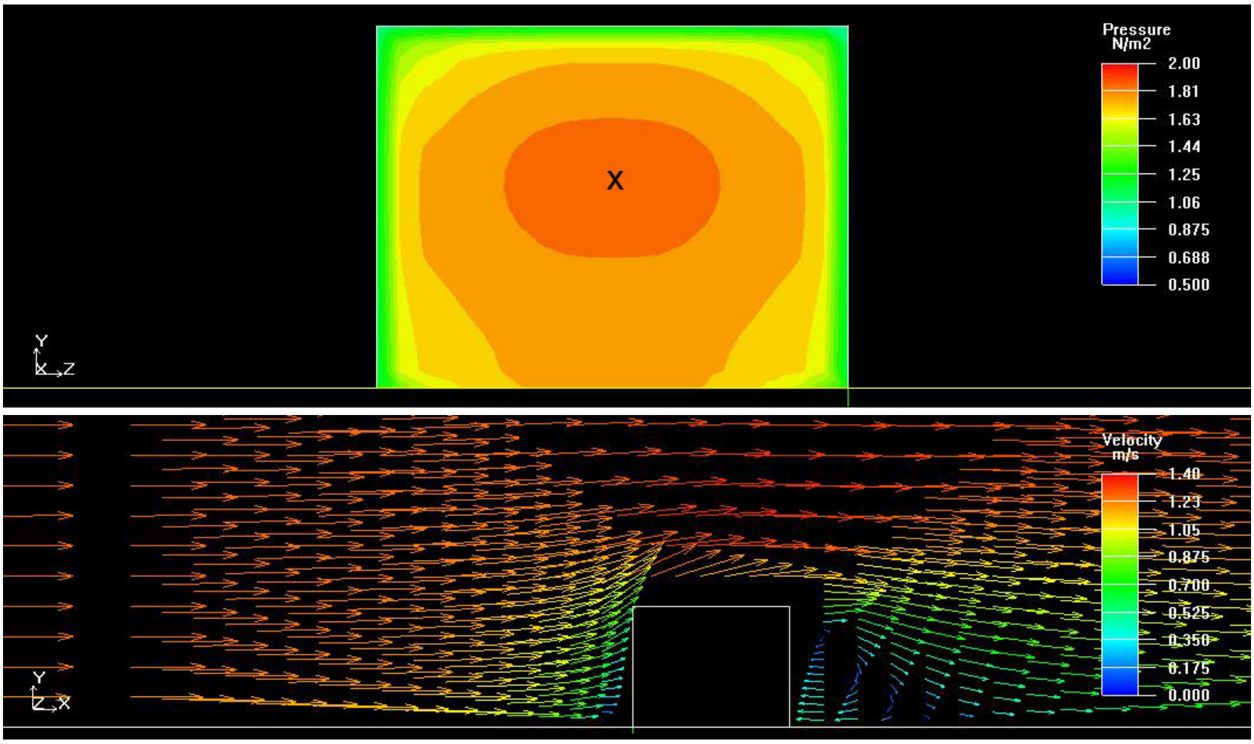

Figure 4: Wind pressure distribution on facade and external airflow for Case 0. 'X' symbol shows the highest pressure on the facade.

(Image: Mohamed, Prasad and King 2010)

4.2.1 Airflow Characteristic and Pressure Distribution

Figures 4 and 5 show the wind pressure distribution on the facade and vertical velocity vector through centre of the room for Case 0 and Case 4, respectively. Based on the images, they show that the wind pressure is more evenly distributed on the facade in Case 0 in comparison to Case 4, where there is more distinct pressure difference and irregular pressure distribution on the facade resulting from the provision of a protruding element. It is found that Case 4 provides greater potential to induce indoor natural ventilation due to greater pressure differences across the facade. It is also found that wind pressure values in Case 4 are much lower than Case 0. Thus it can be concluded that the provision of a horizontal protruding element has changed the external airflow characteristic and wind pressure distribution.

5.0 RESULTS

5.1 Indoor Air Velocity and Age of Air

The following conclusions can be drawn from the results and are outlined in Appendix A, B and C.

The provision of a protruding element on the facade of building has improved the indoor air velocity in many cases. This is shown by an increase of mean air velocity over 50 per cent for Case 5, in comparison with Case 2. For Case 7, the mean velocity increment is increased by 10 per cent in comparison with Case 3. This has resulted from the positioning of openings away from the area of high wind pressure, which is located below the protruding element in Case 7. However for Case 1, the mean air velocity is higher compared to Case 6 due to the uninterrupted position of the upper opening in Case 1 receiving direct wind flow, together with the location of the opening close to top edge of windward wall. In Case 9, the protruding element's width is increased to 2.0 m, resulting in reduction of mean indoor velocity in comparison to 1.0 m width in Case 6.

The width of the protruding element also affected the indoor airflow. Comparing Case 6 and Case 9, it shows that a 0.2 m wide protruding element provides greater pressure difference between two vertically arranged openings in comparison with a 0.4 m width. Thus, Case 6 provides greater indoor mean air velocity.

Comparing Case 2 and Case 5, the provision of protruding element manages to increase the maximum and mean indoor air velocity. Even though the mean air velocity is below 0.25 m/s and unable to be perceived by humans (Szokolay 1980), it is important to note that at an outdoor wind speed of 1.25 m/s, a maximum indoor wind velocity above 0.25 m/s exists in Case 5, and does not exist in Case 2.

For mean age of air, room models with a protruding element have shorter mean age air, except in Case 7. This is because the positions of the openings are within the area of low wind pressure in comparison to Case 2 and Case 3. Among all the models, Case 9

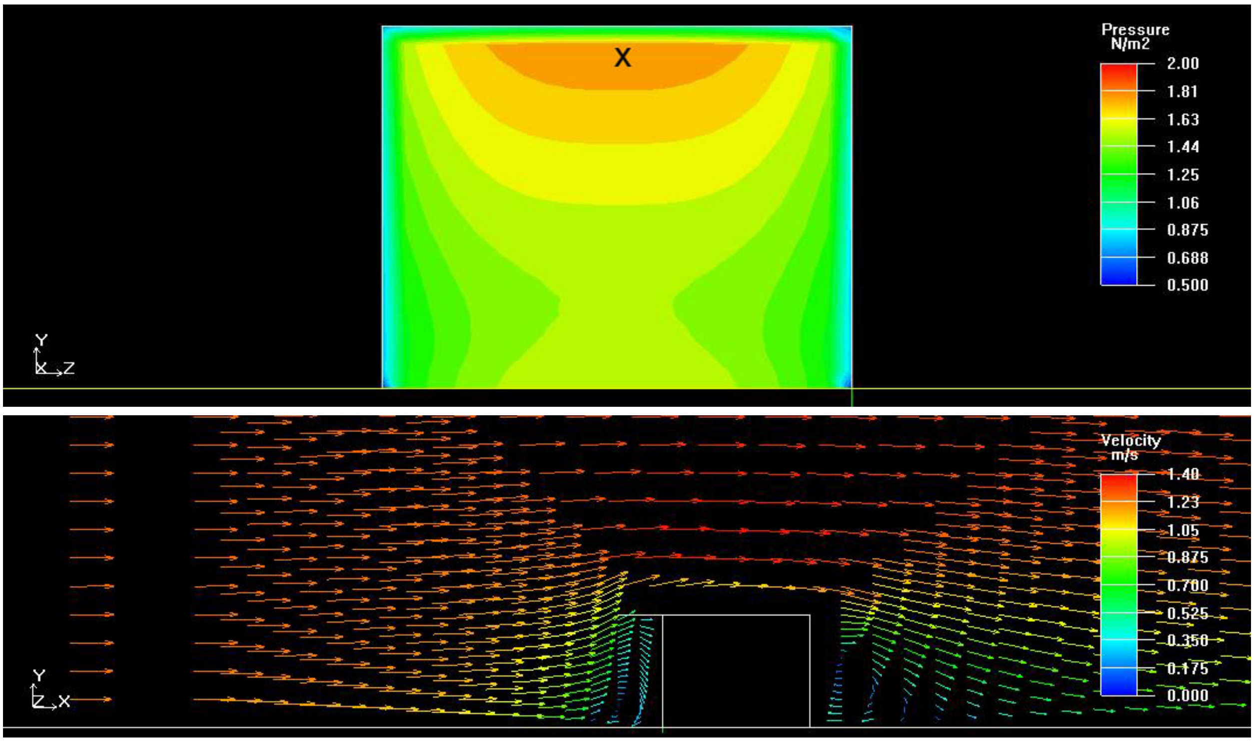

Figure 5: Wind pressure on facade and external airflow for Case 4. 'X' symbol shows the highest pressure on the facade.

(Image: Mohamed, Prasad and King 2010)

has the lowest mean age of air. Therefore, provision of protruding element provides shorter indoor age of air, which leads to better a ventilation rate and a well distributed indoor airflow.

It is observed that the size of opening has an impact on the indoor air flow. This can be seen in Case 5 and Case 8. In case 5, the mean air velocity is 0.056 m/s, whereas in Case 8 it is reduced to 0.038 m/s. The mean age of air in Case 8 is observed to be higher than Case 5 by 13 per cent. Therefore it can be concluded that larger size of opening helps to improve indoor air velocity and ventilation rate.

The number of openings could also influence the mean velocity of indoor air flow. Taking the single opening in Case 5 as a base, providing two openings with the same total opening area, as in Case 6, improves the indoor mean air velocity by 50 per cent. This shows that indoor airflow can be improved by providing more than one opening.

The position of openings also influences the indoor airflow. This can be observed by comparing Case 6 and 7. There is an increase of 58 per cent of mean air velocity in Case 6 in comparison to Case 7. Thus it can be concluded that positioning openings in area which provides an increase of pressure difference between openings can improve indoor air velocity.

6.0 IMPLICATIONS

The provision of veranda on the facade of a building changes the wind turbulence characteristic and the wind pressure distribution on the outside of the building. These changes can be utilised to improve indoor airflow. This study shows that the provision of veranda improves indoor air velocity and lowers the age of air, which subsequently improves indoor ventilation rates and air distribution. The potential of a veranda to induce indoor natural ventilation can be further improved by an appropriate combination of openings which can be achieved by providing multiple openings, increasing their size, and locating them at places with a higher wind pressure difference.

Therefore, it is recommended that veranda be incorporated in building design to improve indoor air flow. However, a more comprehensive study is required to better understand the changes on wind turbulence and pressure distribution characteristics resulting from the provision of veranda in order to optimise the benefit of veranda in inducing indoor airflow. This would include the effects of vertical protrusions and the effects of various wind directions, as these factors also contribute significantly to outdoor and indoor airflow characteristics. This is crucial, as incorrect veranda design may reduce the performance of indoor airflow. As can be observed in this study, the wrong combination of veranda and openings reduces the performance of airflow. This study also shows that a deeper veranda does not necessary mean a better indoor airflow, since the space within the veranda could become a buffer space preventing prevailing wind from penetrating into the indoor environment.

Better understanding of the effects of veranda on indoor airflow provides designers with knowledge on optimising veranda to enhance indoor airflow, especially in the case of a single-sided ventilation strategy. Designing veranda for indoor ventilation performance could also change the perception of designers towards veranda and lead them to design veranda that function as more than just an outdoor space and architectural feature, but also as a device that can improve indoor environmental quality through better ventilation. It is also important to note that optimising veranda design for ventilation performance helps to achieve sustainable development by decreasing reliance on mechanical ventilation, and consequently reduces the consumption of energy and the production of greenhouse gases.

7.0 CONCLUSION

This study found that the provision of veranda in building design changes outdoor and indoor airflows, thus veranda should be carefully incorporated in a building to ensure that it enhances the indoor airflow for occupants' thermal comfort. Based on the room models investigated in this study, it is found that veranda depth and opening configuration play a very important role in deciding indoor ventilation performance, where a correct combination of both factors improves indoor ventilation performance, but an incorrect combination decreases it.

Since this study is limited to a single-storey building with a single room, it does not include the impacts of veranda in a more complex building configurations, such as multi-storey buildings, where the atmospheric boundary layer condition exists and significantly impacts on wind pressure distribution. Hence, a study of the effects of veranda in such condition is necessary as there are many single-sided ventilated multi-storey buildings which have veranda, e.g. studio apartments. For this reason, such a study will be completed in a subsequent investigation.

REFERENCES

Allard, F (ed.) 1998, *Natural ventilation in buildings: A design handbook*, James & James (Science Publishers) Ltd, London, UK

Awbi, HB 1991, *Ventilation of Buildings*, E & FN Spon, London, UK

Chand, I, Bhargava, PK and Krishak, NLV 1998, 'Effect of balconies on ventilation inducing aeromotive force on low-rise buildings', *Building and Environment*, no. 33, pp. 385–396

Cowan, HJ and Smith, PR 2004, *Dictionary of Architectural and Building Technology*, 4th ed., Spon Press (Taylor & Francis Group), London, UK

Department of Infrastructure, Planning and Natural Resources, NSW 2002, *Residential Flat Design Code: Tools for Improving the Design of Residential Flat Buildings*, Government of NSW, Sydney

Fleming, J, Honour, H and Pevsner, N 1991, *The Peguin Dictionary of Architecture*, Penguin Books, London, UK

Fluent Inc 2007, *Airpak 3.0 User's guide*, Lebanon

Givoni, B 1968, 'Ventilation problem in hot countries'. Reserach report to the Ford Foundation, Technion, Building Research Station, Israel Institute of Technology, Haifa, Israel

Givoni, B 1976, *Man, Climate and Architecture*, Applied Science Publishers Ltd, London, UK

Larsen, TS, and Heiselberg, P 2008, 'Single-sided natural ventilation driven by wind pressure and temperature difference', *Energy and Buildings*, no. 40, pp. 1031–1040

Liddament, MW 1996, *A Guide to Energy Efficient Ventilation*, Air Infiltration and Ventilation Centre, Conventry, UK

Mak, CM, Niu, JL, Lee, CT and Chan, KF 2007, 'A numerical simulation of wing walls using computational fluid dynamics', *Energy and Buildings*, no. 39, pp. 995–1002

Malkawi, AM and Augenbroe, G (eds.) 2003, *Advanced Building Simulation*, Spon Press (Taylor & Francis Group), London, UK

Mohamed, MF, Mohd Tahir, M and Prasad, D 2008, 'A study on balcony and its potential as an element of ventilation control in naturally ventilated apartment in hot and humid climate', *International Conference on Construction and Building Technology*, Kuala Lumpur, Malaysia

Oktay, D 2002, 'Design with the climate in housing environments: An analysis in Northern Cyprus', *Building and Environment*, no. 37, pp. 1003–1012

Prianto, E and Depecker, P 2002, 'Characteristic of airflow as the effect of balcony, opening design and internal division on indoor velocity: A case study of traditional dwelling in urban living quarter in tropical humid region', *Energy and Buildings*, no. 34, pp. 401–409

Prianto, E and Depecker, P 2003, 'Optimization of architectural design elements in tropical humid region with thermal comfort approach', *Energy and Buildings*, no. 35, pp. 273–280

Szokolay, SV 1980, *Environmental Science Handbook for Architects and Builders*, The Construction Press, London, UK

Yuan, LJ 1987, The Malay House: *Rediscovering Malaysia's Indigenous Shelter System*, Pulau Pinang, Institut Masyarakat, Malaysia

APPENDICES

The results of indoor air velocity; indoor age of air; and pressure value at the middle of upper and lower openings are tabulated in Appendix A, B and C, respectively.

	Air velocity (m/s)			% of mean indoor air speed to wind speed	Standard deviation
	Min	Max	Mean		
Case 1	0	0.616	0.090	7.20	0.102
Case 2	0	0.120	0.036	2.88	0.031
Case 3	0	0.564	0.048	3.84	0.095
Case 5	0	0.376	0.056	4.48	0.084
Case 6	0	0.511	0.084	6.72	0.103
Case 7	0	0.686	0.053	4.24	0.116
Case 8	0	0.333	0.038	3.04	0.071
Case 9	0	0.475	0.060	4.80	0.080

Appendix A – Data showing indoor air velocity (m/s)

	Min	Max	Mean	Standard Deviation
Case 1	6.61	22.89	17.04	5.49
Case 2	7.23	42.12	27.61	10.23
Case 3	7.49	44.56	27.07	11.73
Case 5	5.76	22.77	16.41	4.93
Case 6	5.97	23.51	15.48	5.27
Case 7	6.93	53.07	32.47	14.02
Case 8	5.77	25.42	17.85	5.79
Case 9	5.67	27.66	15.33	6.28

Appendix B – Data showing indoor age of air (s)

	Pressure (N/m2)		
	Upper opening	Lower opening	Difference
Case 1	0.855	0.904	0.049
Case 6	1.172	1.019	0.153
Case 9	1.162	1.039	0.123

Appendix C – Data showing pressure value at the middle of upper and lower openings for Case 1, Case 6 and Case 9