# The Impact of Balconies on Wind Induced Ventilation of Single-sided Naturally Ventilated Multi-storey Apartment

M. F. MOHAMED[1], D. PRASAD[1], S. KING[1], K. HIROTA[2]

[1]Faculty of the Built Environment, University of New South Wales, Sydney, Australia
[2]Centre for Health Assets Australasia (CHAA), University of New South Wales, Sydney, Australia

*ABSTRACT: The existence of a building along a path of wind flow changes the characteristic of the wind flow including its speeds and directions. The introduction of balconies further changes the characteristic of wind flow close to the building façade, thus creating more complex turbulence characteristics influencing the indoor natural air flow. This study uses Computational Fluid Dynamics (CFD) to examine the impact of balconies on wind induced ventilation of single-sided naturally ventilated apartments in a multi-storey building. This is an early investigation for a more comprehensive study to investigate the impact of balcony on single-sided naturally ventilated high-rise apartments. The main objectives of the present study are: to investigate the impact of balconies on outdoor and indoor airflow characteristics at various apartment heights; and to investigate how configurations of balconies and openings influence the resulting airflow. This study confirms that, at normal wind incidence, the balconies significantly change the external airflow, but also suggests that this will reduce the effectiveness of wind induced ventilation for single-sided ventilated apartment. It is also observed that the configurations of balcony and opening can play an active role in inducing enhanced indoor air flow.*
*Keywords: balcony, single-sided ventilation, wind, multi-storey building, CFD*

## INTRODUCTION

World population has increased rapidly, especially in developing countries. According to the United Nations Population Fund [1], it is estimated that in 2008 more than half of world population is living in urban areas. The increasing number of urban inhabitants leads to the growing need for urban dwellings. With higher urban population density, housing development faces a major difficulty in providing sufficient dwellings within a landscape of already congested urban spaces. Furthermore, the needs to reduce both transportation cost and time, add further pressure to the needs for dwellings within urban vicinity. However, land becomes the major constraint in providing sufficient dwellings with close proximity to workplaces. Thus, the provision of high density dwellings, with higher building plot ratios, is the only option available to cater for the need.

There is a tendency for designers to design buildings in urban contexts which adopt single-sided ventilation, as a result of various factors: development sites in urban contexts, pressure to produce cost efficient development, maximising the number of dwelling units, etc. In spite of the known ventilation effectiveness of facilitating cross ventilation by openings to two or more facades, many residential buildings such as apartments and hotels, adopt plans where only single-sided ventilation is available. Especially in warmer climates, there is therefore a need to give significant attention to the optimization of single-sided ventilation in order to ensure that occupants are provided with thermal comfort and healthy indoor air quality.

Thermal comfort and healthy indoor air quality are depending on various factors. Two of the important factors are mass ventilation rate and air velocity. Although, sufficient ventilation can be achieved naturally or mechanically, from a general sustainability perspective, natural ventilation is a preferred option because it is environmental friendly and uses less energy. Hence, there is a need to better understand passive design strategies to improve indoor airflow for single-sided ventilated buildings. One such passive strategy is appropriate façade reliefs.

There are a number of studies [2,3,4] of the single-sided ventilated building with façade relief. These include the study of wing walls at two openings in a single-sided ventilated room by Givoni [5] in the 1960’s which remains seminal. As Givoni demonstrated, façade relief can significantly improve the indoor airflow in response to available wind velocity, particularly as incident wind direction varies from normal.

Façade relief can more generally be in the forms of opening configurations, wing walls, balcony, louvers, overhangs, etc. Among all the forms of façade reliefs, the balcony is selected for this study because of a range of factors: balconies offer a complex set of other amenities for which they are widely incorporated in buildings without knowing their impact on indoor ventilation, but the most important is the lack of research looking into the relationship between balcony and indoor airflow in single-sided ventilated buildings. There are some studies on balconies and many studies of aspects of single-sided ventilation, but done separately.

The existence of a building along a path of wind flow changes the characteristic of the wind flow including direction and speed. When wind approaches in a perpendicular direction to a tall building façade, the wind changes its direction. This includes movement to the left, right, upwards and downwards [6,7,8]. Introduction of protruding elements, such as wing wall and balcony, will further changes the characteristic of wind flow. A balcony has a horizontal protruding element which resists the vertical movement of air. Therefore, the vertical wind flow resulting from the interaction between wind and building façade is further affected by the existence of the balcony, thus creating a more complex turbulence characteristic. In short, even under an overall condition of wind direction normal to the façade, local wind direction for any particular space/opening configuration within that façade will vary significantly from the normal.

This study looks into the impact of balconies on wind induced ventilation of a single-sided naturally ventilated apartment in a multi-storey building. The main objectives of the study are: to investigate the impact of balconies on outdoor and indoor airflow characteristics at various apartment height; and to look into how configurations of balconies and openings influence the resulting airflow. It is important to note that this study is continuation of a previous study of balconies at a single-sided ventilated cell [9], and itself a preliminary investigation prior to a larger study on the impact of wind induced ventilation on single-sided ventilated high-rise apartments.

## COMPUTATIONAL FLUID DYNAMICS

This study uses Computational Fluid Dynamics (CFD) to create a numerical simulation of balconies at a multi-storey apartment. CFD has been recognised as a computational method capable of solving ventilation problem quickly and economically. However, the use of CFD is still prone to produce errors and inaccuracy due to various reasons ranging from limitation of turbulence models to inaccurate simulation parameters and key data, and thus it requires verification. Presently, this is done by comparing simulation results with work by Chand et al [10]. The software used for the study is Airpak 3.0 which uses FLUENT CFD solver engine. The turbulence model used is standard two equation k-ε turbulence model. In order to limit the computing time, the numerical elements and nodes are limited to approximately two million - which appears able to provide acceptable results to achieve the objectives of this study.

**CFD Simulation Setup** In this study, the 1:30 wind tunnel scaled model by Chand et al. is changed to real scale model for CFD simulation. The basic model is a building block of 5 storey height with 30 single-sided naturally ventilated apartments of 3.0m floor to floor height. Based on the basic model, other variant models are constructed and tested using CFD. For Case 1 and Case 2, the building models are similar to that used by Chand et al. in their wind tunnel experiment. These pilot models are used as references for CFD verification, by comparing their results to the completed wind tunnel work by Chand et al.

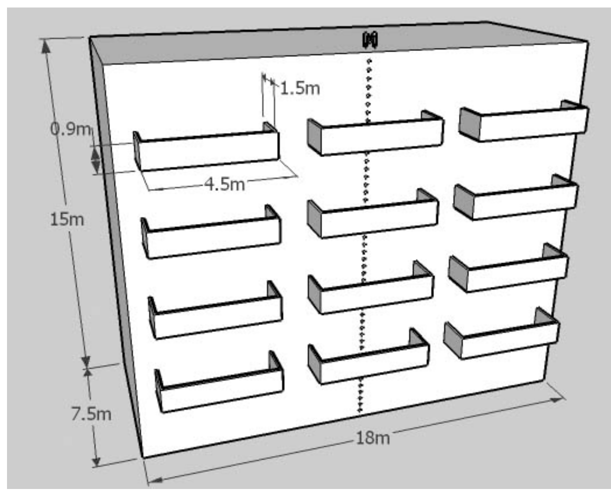


*Figure 1: The real scale pilot model (Case 1) showing dimensions of the model and location of observation points.*

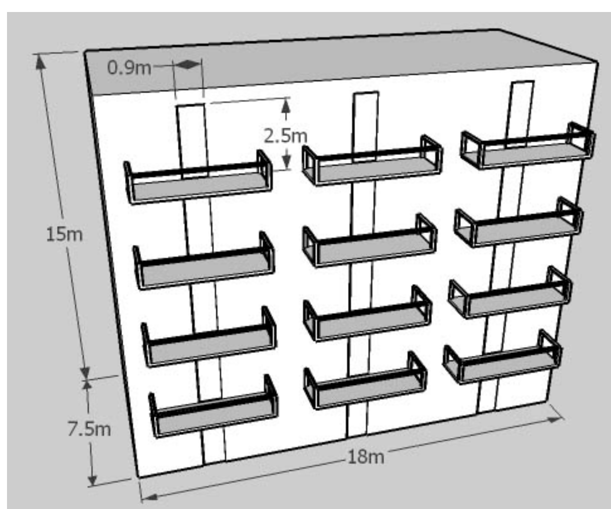


*Figure 2: The image of the Case 6 model showing 100% porosity balustrade with vertical opening.*

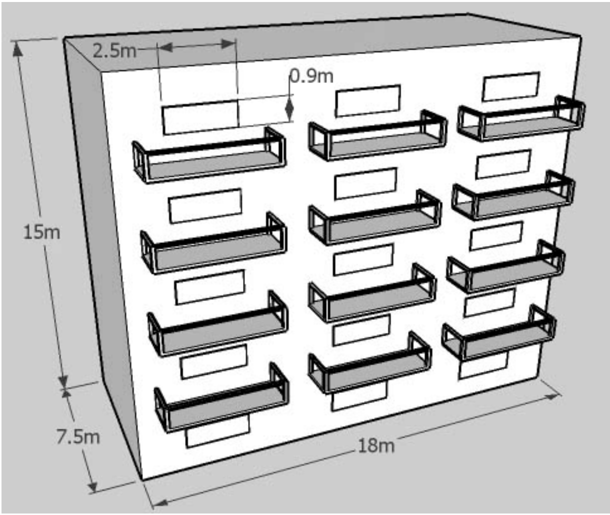


*Figure 3: The image of the Case 8 model showing 100% porosity balustrade with horizontal opening*

Figure 1 shows the model of Case 1 in which each apartment has a balcony with solid balustrade. Nine (9) equidistant observation points are positioned at every floor of middle apartments for all models. Other than Case 1, all balconies are without solid balustrade and are assumed to have 100% porosity. Three (3) different balcony widths are simulated: 0.75m, 1.5m and 3.0m.

For indoor airflow simulation, Case 6, 7 and 8 are simulated with an uninterrupted opening, dimensioning 0.9m x 2.5m but arranged vertically for Case 6 and 7, and horizontally for Case 8. Figure 2 and Figure 3 show the model configurations of Case 6 and 8, respectively. All models simulated in this study are listed in Table 1 which consists of 10 models.

*Table 1: The list of the simulated models together with their configurations and wind directions.*

| Case | Balcony Width (m) | Wind Incident angle (°) | Opening arrangement (0.9x2.5m) |
|---|---|---|---|
| 1 (Pilot model) | 1.5 | 90 | - |
| 2 | - | 90 | - |
| 3 | 1.5 | 90 | - |
| 4 | 0.75 | 90 | - |
| 5 | 3.0 | 90 | - |
| 6 | 1.5 | 90 | Vertical |
| 7 | - | 90 | Vertical |
| 8 | 1.5 | 90 | Horizontal |
| 9 | - | 45 | - |
| 10 | 1.5 | 45 | - |

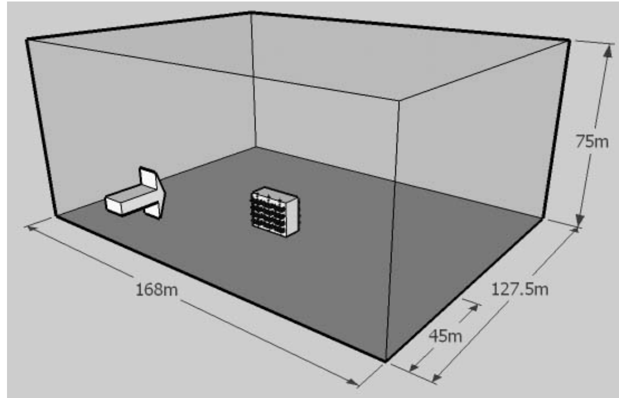


*Figure 4: CFD domain for wind model with an arrow showing normal wind direction.*

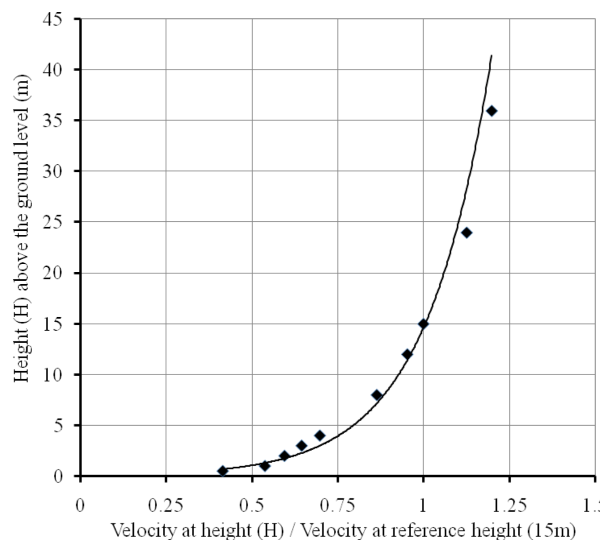


*Figure 5: ABL wind speed profile at the test section.*

This study simulates a standalone building model without existence of building within its proximity (Figure 4). It is limited to wind induced ventilation only with an atmospheric boundary layer (ABL) condition (Figure 5) and wind speed of 3.0m/s at 15m height above ground level. This study only tested two wind directions: normal to building façade (90°) and at an angle of 45°. For indoor air flow analysis, this study is only concerned with the middle apartments.

## ANALYSIS OF RESULTS

The pressure coefficient, $C_p$, values along test section at the windward building façades of all models are shown in a graph (Figure 6). Pressure coefficient, $C_p$, is a dimensionless unit to express the wind pressure. It is derived from the following equation:

$C_p = (p - p_s) / 0.5dV^2$

- $C_p$ = Pressure coefficient;
- p = Measured surface pressure on the model;
- $p_s$ = Free stream static pressure;
- V = Free mean wind speed at roof level height of the model;
- d = Density of air.

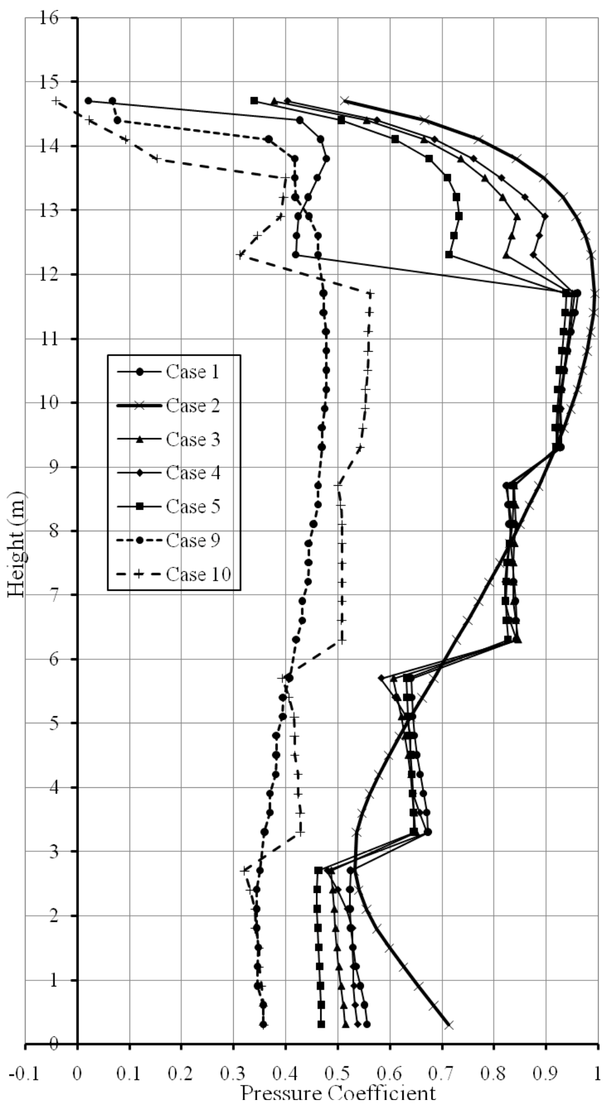


*Figure 6: The $C_p$ values at the middle (M) of windward building façades for Case 1, 2, 3, 4, 5, 9 and 10.*

The simulation results of Case 1 and Case 2 (Figure 6) are first compared to the work by Chand et al for reference to ensure that the results are within acceptable range. The comparison shows that the simulation results of $C_p$ distribution along the test section have discrepancies on exact $C_p$ values in comparison to Chand et al's work. However, the results are accepted to be within a reasonable range since the overall $C_p$ distributions of both studies have similar trend of distributions. In addition, the simulated pattern of external wind flow (Figure 7) are also similar to the description by ASHRAE [6] and Holmes [7] where the wind flow changes towards various directions with stagnation point for Case 2 at the area just above the mid height.

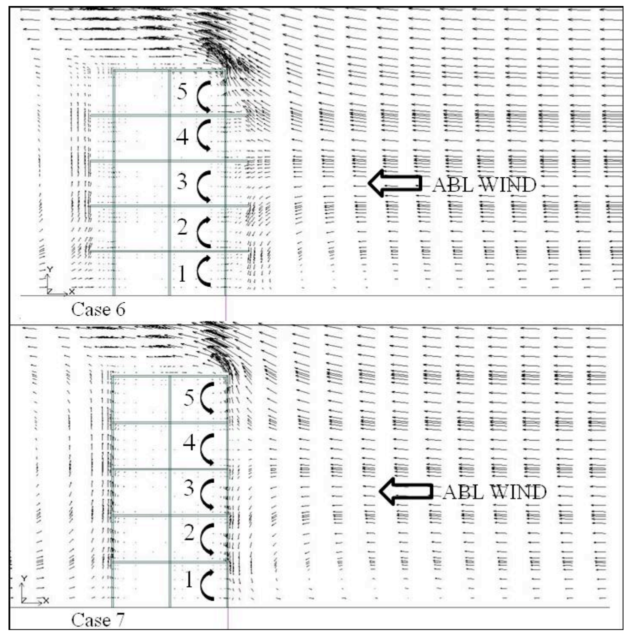


*Figure 7: Sections of models in Case 6 and 7 showing indoor airflow of the middle apartments. An arrow shown within all the five (5) apartments in each case indicates the vertical direction of indoor airflow.*

Figure 6 shows that an introduction of balconies significantly changes the distribution of $C_p$ on the building façades. These changes can be observed by comparing Case 2 with Case 1, 3, 4 and 5. The provision of balconies has reduced the wind pressure difference across the façades. Reduction of pressure difference across building façade of an apartment may reduce the potential of wind to induce indoor air flow in a single-sided ventilated apartment (since openings serving as inlet and outlet can only be provided at that single façade).

The provision of balconies has also developed a higher wind pressure at the façade of the building. This can be seen in apartment 2, 3 and 4 of Case 10; and in apartment 2 and 3 of Case 1, 3, 4 and 5. In the case of cross ventilation, development of higher wind pressure at the building façade helps to improve indoor airflow due to potential of higher pressure difference between openings at two different façades. But, this is not the case for single-sided ventilation. The result of poor indoor airflow at apartment 3 in Case 6 (Figure 8) confirms that the equally developed high wind pressure across the façade of single-sided ventilated apartment with the given opening configuration does not provide positive contribution in improving indoor airflow.

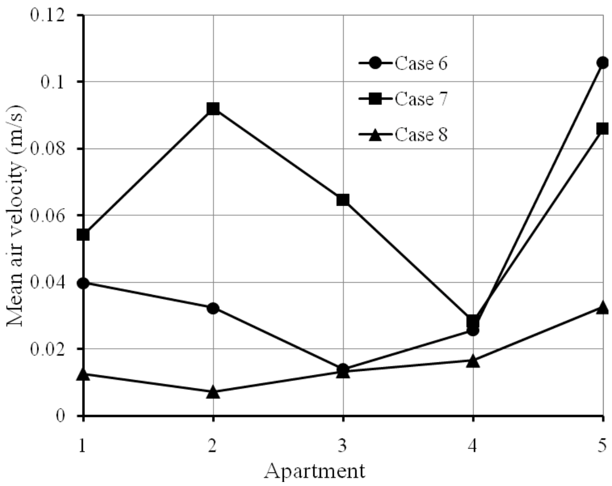


*Figure 8: Graph showing indoor mean air velocity for the apartment 1, 2, 3, 4 and 5 in Case 6, Case 7 and Case 8.*

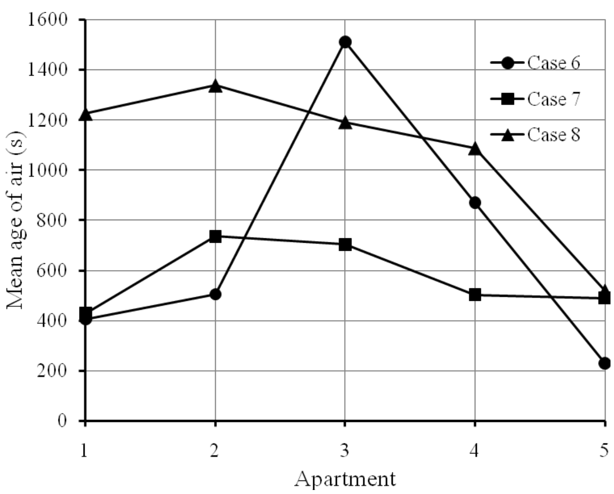


*Figure 9: Graph showing indoor mean age of air for apartment 1, 2, 3, 4 and 5 in Case 6, Case 7 and Case 8.*

Figure 8 show that the provision of balconies (Case 6) has significantly reduced the mean indoor air velocity at apartment 2 and 3; but with a slight reduction at apartment 1. Figure 9 shows that the provision of balconies has resulted in significant increase of mean age of air at apartment 3 and 4, while the provision of balconies only results in slight improvements of mean age of air at Apartment 2 and 5. These results further show that the provision of balconies reduces the effectiveness of wind induced natural ventilation for single-sided apartment. This appears to be due to the areas between the floors of balconies acting as buffers which create complex air turbulence and subsequently reduce the penetration of wind flow. This is shown in the velocity vectors diagram of Case 6 in Figure 7. Figure 7 also shows the vertical air movement directions for all middle apartments in Case 6 and 7. The provision of balconies has caused change in direction of vertical air movement at Apartment 3.

In Case 6, the worst indoor air flow occurs at apartment 3 with mean air speed of less than 0.04m/s and mean age of air above 1500 seconds. However, the best indoor air flow for Case 6 is at the top apartment. For Case 7, the slowest mean air speed is at level 4, whereas, apartment 5 have highest mean air speed and closely followed by apartment 2. The reason behind the poor performance of indoor air flow at apartment 3 for Case 6 and apartment 4 for Case 7 is the position of those apartments at the stagnation zones, where these are the zones in which the wind direction changes its direction upwards and downwards. Overall, Case 7 performs better than Case 6.

Configurations of balconies also influence the characteristic of external and internal air flow. Figure 6 show that the increased width of balcony reduces the value of $C_p$ on the building façade. This can be seen by comparing the graph of Case 3, 4 and 5. Among all the three cases, 3.0m width developed the lowest $C_p$ across the facade, while 0.75m and 1.5m give almost similar results at apartment 2, 3, and 4. However, more distinctive $C_p$ values resulted from width variations can be observed at the façades of top and bottom apartments.

Generally, the results of this study show that the provision of balconies for single-sided ventilated apartment reduces the indoor natural ventilation due to wind. Therefore, it is necessary to optimise the wind induced ventilation at the apartment by utilising other means such as opening configurations. Correct opening configurations are vital to induce indoor airflow by optimising the interaction with changes in external airflow due to provision of balconies. Case 6 and 8 incorporate vertical and horizontal arrangements of rectangular openings, respectively. Figure 8 and 9 show that the vertically arranged rectangular opening performs better than the horizontally arranged opening. This is due to optimisation of pressure difference created at the top and bottom of the apartment's facades.

Referring to Case 9 and 10 in Figure 6, for wind angle of 45°, it indicates that there are also changes on distribution of $C_p$ due to the provision of balconies. The introduction of balconies results in slight increments of pressure coefficient values at level 2, 3 and 4, in which indicates potential indoor ventilation improvement.

## CONCLUSION

The study shows that the balconies significantly change the external air turbulence and airflow characteristics. In other words, balconies alter the wind pressure distribution on the façade of the building. The results indicate that, at 90° wind incidence, the introduction of 1.5 m width balconies reduces the effectiveness of outdoor wind to induce indoor natural ventilation in single-sided naturally ventilated apartment. However, a further study is needed to investigate the impact of the balconies under conditions of various wind angles.

In addition to this, incorporation of inappropriate configuration of openings at the balconies could further reduce the indoor airflow. Thus, in order to optimise indoor airflow, it is important to understand the changes of outdoor airflow created by the provision balconies and to provide appropriate opening and balcony configurations. This study also demonstrates that, as a result of ABL condition and building height, the indoor air flow of an apartment varies considerably according to the its height from ground level as well as its location at the building block.

Introduction of balconies in a larger and higher building may give different result due to various factors such as ABL condition and building scale. Further study on the impact of balconies on a much taller single-sided naturally ventilated apartment building is to be taken by the authors.

## REFERENCES

1. UNFPA (2007). UNFPA: State of world population 2007: Unleashing the population of urban growth, United Nations Population Fund (UNFPA).

2. Mak, C. M., Niu, J. L., Lee, C. T. and Chan, K. F. (2007). A numerical simulation of wing walls using computational fluid dynamics. *Energy and Buildings,* 39, p. 995-1002.

3. Papakonstantinou, K. A., Kiranoudis, C. T. and Markatos, N. C. (2000). Numerical simulation of air flow field in single-sided ventilated buildings. *Energy and Buildings,* 33, p. 41-48.

4. Alloca, C., Chen, Q., and Glicksman, L. R. (2003). Design analysis of single-sided natural ventilation. *Energy and Buildings,* 35, p. 785-795.

5. Givoni, B. (1976) Man, climate and architecture, London, Applied Science Publishers Ltd.

6. ASHRAE (1997). 1997 ASHRAE Handbook: Fundamentals., Atlanta, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc.

7. Holmes, J. D. (2001). Wind loading of structures, London, Spon Press.

8. Ismail, A. M. (1996). Wind-driven natural ventilation in high rise buildings with special reference to the hot humid climate of Malaysia. Cardiff, University of Wales College of Cardiff.

9. Chand, I., Bhargava, P. K. & Krishak, N. L. V. (1998). Effect of balconies on ventilation inducing aeromotive force on low-rise buildings. Building and Environment, 33, p. 385-396.

10. Mohamed, M.F., Prasad, D., King, S. (2008). An investigation of the impact of veranda on the indoor air flow of single-sided naturally ventilated building. In *3rd International Solar Energy Society Conference – Asia Pacific Region, Incorporating the 46th ANZSES Conference*. Sydney, Australia, November 25-28.