VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

POTENTIAL OF VOIDS TO ENHANCE NATURAL VENTILATION IN MEDIUM COST MULTI-STOREY HOUSING (MCMSH) FOR HOT AND HUMID CLIMATE

Fakhriah Muhsin[1], Wardah Fatimah Mohammad Yusoff[1], Mohd Farid Mohamed[1], Mohammad Rasidi Mohammad Rasani[2] and Abdul Razak Sapian[3]
[1]Department of Architecture, Faculty of Engineering and Built Environment, Universiti Kebangsaan Malaysia, Selangor, Malaysia
[2]Department of Mechanical and Materials Engineering, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia
[3]Department of Architecture, Kulliyyah of Architecture and Environmental Design, International Islamic University Malaysia, Kuala Lumpur, Malaysia
E-Mail: fakhriahmuhsin@yahoo.com

ABSTRACT

The objective of this study is to discuss the potential of voids in Medium Cost Multi-Storey Housing (MCMSH) for hot and humid climate. The result has a significant to identify the suitable configurations of voids for better passive design strategy. In this study, the performance of voids for MCMSH has been studied by using CFD simulation. This study provides a result of different configurations of voids for the studied buildings. The results suggest the appropriate parameter that affects the enhancement of natural ventilation for MCMSH to be adapted in hot and humid climate. The discussion forms a basic framework of void's proportions in MCMSH to serve better environmental living environment for the MCMSH's occupants.

Keywords: natural ventilation, ventilation rate, voids, medium cost multi-storey housing, CFD.

INTRODUCTION

In recent years, natural ventilation in buildings has received increasing attention that reflecting the interest in sustainability and green energy buildings. Almost all urban areas are characterized by rise buildings and high density. Under this circumstance, achieving comfortable and healthy indoor environments with minimizing energy consumption becomes a very challenging architectural and engineering issue [1, 2]. Thus, numerous studies revealed that natural ventilation plays an important role to provide better indoor air quality (IAQ), thermal comfort and save energy consumption in buildings [1, 3-7].

According to Moo-Hyun and Ji-Hyeon [7], natural ventilation is approved as the most effective and energy efficient method used in multi-storey buildings. However, most multi-storey buildings do not really concern natural ventilation aspect (e.g. do not allow a good control of the ventilation rate etc.) [5, 7-9]. The role of natural ventilation in providing a comfortable and healthy environment forms the basis for the design criteria for residential buildings [10]. One of the important design criteria to enhance natural ventilation for deep plan buildings (rise buildings) is void [10].

CFD model has been adopted in this study, which has becomes as the main tool in an extensive number of studies concerning natural ventilation performance. It has been used for many geometrically complicated buildings, such as Nagai and Karabuchi used CFD to decide the coefficients in the nodal model for a high-apartment building with central void space throughout the height of the building in Japan [11]. Pimolsiri and Steve [12] used CFD to analyse the potential of ventilation shafts in rise residential buildings in Bangkok. Mohamed [9] conducted CFD to induce wind-driven natural ventilation for single-sided apartments. Sapian A. R. [13] used CFD to estimate the vertical pressure distribution and to investigate the potential of the proposed design solution for High-Rise Low-Cost Residential Building (HRLCRB). James O.P. and Chun-Ho L. [6] used CFD to explore the effects of building interference on natural ventilation. Moo-Hyun K. and Ji-Hyun H. [7] used CFD to predict the various performance of hybrid ventilation system in apartments. However, there is less study on the potential of void to estimate horizontal wind pressure distribution for deep plan buildings in hot and humid country.

NATURAL VENTILATION

'Natural ventilation' is defined as supply of fresh air, together with the removal of aged air through an indoor space, by natural [6]. According to Cristian Ghiaus [14], 'natural ventilation' means opening a window to let fresh air into a room. Natural ventilation in buildings is caused by the pressure difference created between inlets and outlets of the building envelope, as a result of natural driving forces; (i) Wind induced ventilation (caused by the pressure distribution around buildings), and (ii) Buoyancy induced ventilation (created due to the thermal differences, hence density differences between the air inside and outside a building [5, 12, 15-17].

In hot and humid climate, natural ventilation is very important to provide a comfortable indoor thermal condition by encouraging the evaporation of moisture from the skin and increasing the rate of the skin's heat dissipation through convection. The efficiency of natural ventilation can be improved by measure of how effective the internal air motion is in distributing the fresh air that enters the space [10]. The effectiveness of indoor natural ventilation is determined by the prevailing outdoor conditions, which are microclimate (wind speed, temperature, humidity and surrounding topography) and

ARPN Journal of Engineering and Applied Sciences

the building itself (orientation, number of windows or openings, their size and location) [5].

VENTILATION RATE

Ventilation rate for natural ventilated building is necessary for both comfort and energy reasons [4, 5, 18]. Ventilation rate can be predicted by using pressure differences across a sealed building, size and airflow discharge characteristics of the building's openings. The common requirement for a minimum fresh air flow rate of about 10 litres s-1 per person is based on the removal of body odours and this is usually sufficient to cope with other contaminants generated within occupied building [10]. Ventilation rate should be much larger in poorly insulated buildings[18].

According to Chaobin *et al*. [19], ventilation rate should meet the local requirements for the sake of occupants' health and comfort. Table-1 states the ventilation rate requirements for residential buildings according to Uniform Building By-Laws 1984 [20], American Society of Heating, Refrigerating and Air Conditioning Engineers [21] and The Chartered Institution of Building Services Engineers [22].

Table-1. The ventilation rate requirements for residential buildings according to UBBL, ASHRAE and CIBSE.

Country	Malaysia	United States		United Kingdom
Standard	Uniform Building By-Laws 1984 [G. N. 5178/85]	ASHRAE 62.1-2013		CIBSE: Concise Handbook (Guide B)
Unit	Air change per hour (ACH)	Fresh air per person (L/s·person) +	Fresh air per const. area (L/s·m^2)	Air change per hour (ACH)
Value	0.14	2.5	0.3	0.5 - 1
Source:	*[20]*	*[21]*		*[22]*

The required ventilation rate as stated in Table-1 can be easily achieved by natural means. The minimum ventilation rate requirement for hot and humid climate such as Malaysia is 0.14 ACH [20]. Ventilation rate, Q, for natural ventilated building can be measured by using equation:

$$Q = C_d \, A_w \sqrt{2 \Delta p / \rho} \tag{1}$$

where Q is the ventilation rate in cross ventilation due to wind effect only (m^3s^{-1}), $C_d$is opening's discharge coefficient, A_w is opening area (refer to Equation (2), Δp is pressure difference (Nm^{-2}) and ρ is air density (kgm^{-3}). A_w value is received by using equation:

$$\frac{1}{A_w^{\,2}} = \frac{1}{A_i^{\,2}} + \frac{1}{A_o^{\,2}} \tag{2}$$

where A_i and A_o are the inlet's and outlet's cross-sectional area (m^2). In order to improve ventilation rate, Q, when opening sizes are fixed, Δp value can be adjusted (refer to Equation (1). To account for real world effects, C_d is introduced and for small openings, a representative value for C_d is 0.65 [4].

NATURAL VENTILATION FOR MULTI-STOREY HOUSING

'Multi-Storey Housing' can be defined as a house building with several levels or floors [23, 24]. According to Jan Krebs [25], 'Multi-Storey Housing' combines several rooms or units in a complex building, arranged adjacent to or above each other on several floors. The characteristics of natural ventilation driving forces are influenced by the height of the building. Thus, based on previous study, this study suggests that there are four (4) types of multi-storey housing height (as stated in Table-2).

Table-2. Four (4) types of multi-storey housing height.

Types	Building height [26]	Building height [5]	Summarization
Low-rise	≤ 4 storeys	1 - 2 storeys	1 - 4 storeys
Medium-rise	5 - 15 storeys	3 - 6 storeys	5 - 15 storeys
High-rise	16 - 50 storeys	≥ 10 storeys	16 - 50 storeys
*Super high-rise (skyscraper)	> 50 storeys	Not stated	> 50 storeys
Source: Building Type Basics for Housing: 2nd Edition [26] & Ventilation Systems: Design and Performance [5]			

As stated in Table-2, medium rise is selected for pilot study of MCMSH. Awbi [5] claimed that building geometry determines the natural ventilation being used for the building; (i) distributed and linear building forms tend to use single-sided or cross ventilation principles, (ii) while more compact buildings such as rise buildings, use stack ventilation either by utilization of voids or chimneys.

ARPN Journal of Engineering and Applied Sciences

PROPOSED STRATEGY: VOIDS

'Void' means air well / atria, which is normally in the centres of a building [27]. An air well is a passive architectural feature which is adopted for natural lighting and ventilation [9, 13, 28]. According to Shuzo Murakami *et a*l. [29], voids in the buildings bring advantages in the architectural, environmental, and structural aspects which can be summarized as follow: (1) indoor environmental control with a low environmental load using the potential of outdoor environment will be possible. The voids will facilitate natural ventilation and enable the IAQ to be controlled, (2) solar shading performance will be improved by introducing voids in the buildings. The voids will act as ventilation spaces and this enable passive maintenance of a good indoor comfort, (3) Proper isolation or connection for each room will be possible by the use of voids. The voids will become as adequate buffers (buffer spaces between private and public living spaces) into living spaces will make it possible to limit the invasion of private living and to achieve less stressful high-density neighbourhood units, and (4) Variegated living spaces can be created by combining rooms with voids.

Previous studies suggested that introducing voids in buildings can improve natural ventilation indoors. Tomoko Hirano *et al.* [30] revealed that the building model with a void ratio of 50% is more effective than the building model with a void ratio of 0% in terms of air change rate (about four times larger) and average wind velocity at the openings (around 30% faster). Also, previous researchers revealed that the void create positive pressure differences, which allows the windward façade of the rear block to receive the wind that flow through the void [13, 28]. Nasibeh Safadi *et al.* [31] revealed that void does affect the improvement of indoor comfort of its adjacent areas. Therefore, this study conducts a pilot study on MCMSH as an exercise to study the potential of voids to improve natural ventilation in MCMSH.

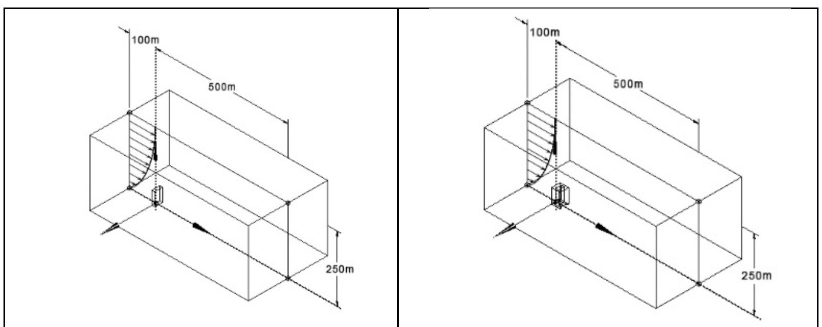
METHOD AND PROCEDURE

CFD model: Geometry, grid, boundary conditions and solver setup

This study evaluated void's ability based on venturi effect principles. The venturi effect refers to the increase of the fluid velocity due to a decrease of fluid pressure in a constricted area [32]. Figure-1 shows the domain set up for rise building with internal void (12 storeys). The blockage ratio for the CFD model is set at 2% to avoid blockage effect and this ratio is less than 3% as suggested by Yoshihide Tominaga *et al.* [33]. The inlet is set to have an atmospheric boundary layer (ABL) wind profile with an exponent, α = 0.28, by using power law:

$$\frac{V_z}{V_g} = \left(\frac{Z_z}{Z_g}\right)^{\alpha}$$

where V_z is the wind speed at height Z_z, m/s. Wind speed, V_g is set to 1 m/s at height of 10 m, Z_g. The governing equation is solved using ANSYS CFX 14.5. The wind angle used is fixed to perpendicular wind, 0° only. Figure-1 illustrates the inlet set up to create atmospheric boundary layer (ABL) wind profile.



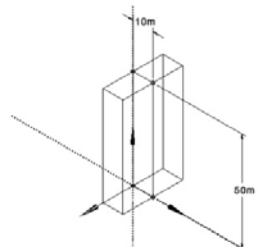
Model A (without void)	Model B (with void)

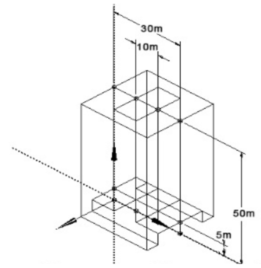
Figure-1. Inlet set up to create atmospheric boundary layer (ABL) wind profile.

The standard k-epsilon (k-ε) model is adopted because it is consistent and stable to predict airflow for multi-storey buildings [6, 12, 34]. There are two experimental models were sized; (i) Model A (without void) was sized 10m x 30m x 50m (length x width x height), (ii) Model B (with void) was sized 30m x 30m x 50m (length x width x height) with internal void in dimension 10m x 20m (length x width) at the middle of the model. The through openings at ground level with dimension 5m x 20m (height x width) is also incorporated in the Model B (as shown in Figure-2).

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com





Model A (*without void*)	Model B (*with void*)

Figure-2. Model A (without void) and Model B (with void) set up in CFD.

MESH INDEPENDENCE STUDY

Tetrahedron meshes are applied for both models. Table-3 states the comparison of meshing in the same ABL wind setting profile with wind angle to perpendicular wind, 0°, for flat façade model.

Table-3. Comparison of average wind pressure (Nm^{-2}) with different meshing.

h / H	6.8 million	2.2 million	1.9 million	0.6 million	0.47 million
0	0.00	0.00	0.00	0.00	0.00
1	1.15	1.13	1.11	1.11	1.09
2	1.17	1.15	1.14	1.34	1.12
3	1.20	1.17	1.17	1.17	1.15
4	1.22	1.20	1.20	1.20	1.19
5	1.25	1.23	1.23	1.22	1.21
6	1.27	1.26	1.25	1.25	1.24
7	1.30	1.28	1.27	1.27	1.26
8	1.31	1.30	1.29	1.29	1.28
9	1.33	1.31	1.30	1.30	1.29
10	1.34	1.32	1.31	1.31	1.30
11	1.34	1.33	1.32	1.32	1.31
12	1.35	1.33	1.33	1.34	1.33
mean:	1.27	1.25	1.24	1.26	1.23

As stated in Table-3, the total number of elements approximately 1.9 million is decided for this study. Thus, CFD model with void is also applied the same mesh setting, which is approximately 3.5 million.

VALIDATION OF CFD MODEL BY WIND TUNNEL EXPERIMENT DATA

The validation of CFD models was done before it was adopted as a tool of this study. The comparison between CFD models and experimental measurements, such as wind tunnels, has received considerable coverage and has led to the improvement of the models [10]. Thus, to validate the outdoor airflow, wind pressure distributions on CFD model is compared with wind tunnel (WT) experiment data from the University of Wales College of Cardiff [28]. Figure-3 and Figure-4 illustrate the comparison of wind pressure distributions on windward and leeward at central line facades of both models (with and without voids) at wind angle of 0°.

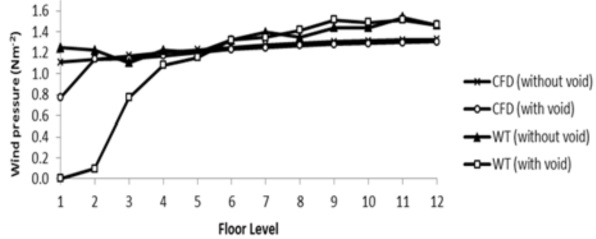


Figure-3. Comparison of wind pressure distributions on windward facades of both models (with and without voids) at wind angle of 0°.

VOL. 12, NO. 10, MAY 2017 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

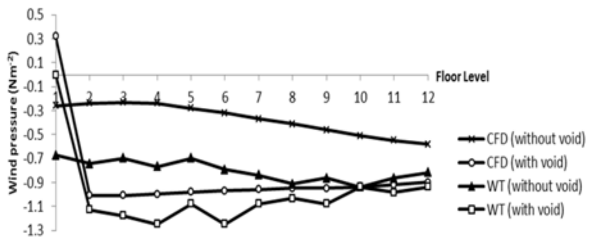


Figure-4. Comparison of wind pressure distributions on leeward facades of both models (with and without voids) at wind angle of 0°.

Table-4 states the comparison of average wind pressure distributions between WT and CFD model on windward and leeward at central line facades of both models (with and without voids). Wind pressure at level 1 and level 2 for both WT and CFD model is less regarding the effect of podium to compare with the flat façade (without voids) models, which have no podiums.

The average relative percentage (%) difference between WT and CFD model at windward facades is 6.8% for Model A and 8.2% for Model B. However, the average relative percentage (%) difference between WT and CFD model at leeward facades is 53.75% for Model A and 13.13% for Model B. Similarly, previous studies revealed that there is a systematic underestimation of the absolute value of wind pressure by CFD at the leeward façade [35, 36] Figure-5 illustrates the pattern of air velocity distributions at both models, which revealed that the provision of voids changes the airflow pattern at the leeward facades. As a result, Δp value was changed. Thus, this study suggests that the increasing of Δp value can increase ventilation rate, Q for indoor living environment (refer to Equation (1).

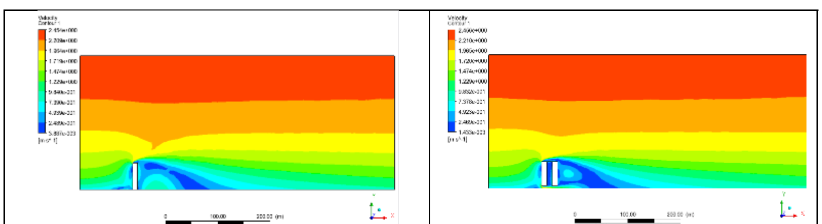
RESULT AND DISCUSSIONS

Performance of voids to enhance ventilation rate

The wind pressure data from CFD simulations and wind tunnel experiments are used to predict ventilation rate, Q by adopting Equation 1.1. Figure-6 illustrates the comparison of ventilation rate for of Model A (WT), Model B (WT), Model A (CFD), Model B (CFD), Model C (the modification of Model B with enlarged 50% of Model B's void).

Table-4. Comparison of average wind pressure distributions on windward and leeward at central line facades of both models (with and without voids) from wind tunnel data and CFD simulations.

	Average wind pressure (Nm^{-2})					
	Windward			**Leeward**		
	WT	**CFD**	**dif.** (%)	**WT**	**CFD**	**dif.** (%)
Model A (*without void*)	1.33	1.24	6.8	-0.80	-0.37	53.8
Model B (*with void*)	1.10	1.19	8.2	-0.99	-0.86	13.1



Model A (without void) | Model B (with void)

Figure-5. Comparison of air velocity distributions between Model A (with void) and Model B (with void).

ARPN Journal of Engineering and Applied Sciences

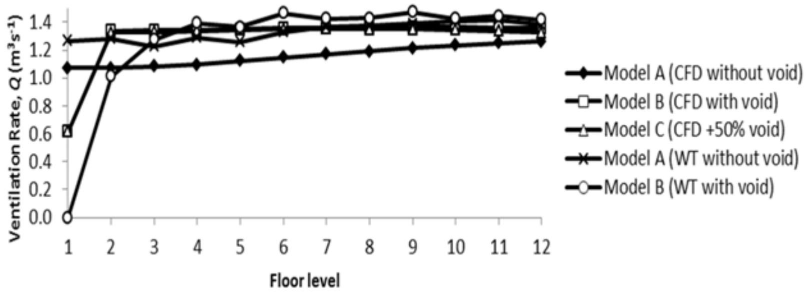


Figure-6. Comparison ventilation rate (Q) of Model A (WT), Model B (WT), Model A (CFD), Model B (CFD) Model C (CFD +50% of Model B's void) at wind angle of 0°.

Figure-6 indicates that the provision of voids in MCMSH increased the ventilation rate of the studied building. Table-5 states the comparison of ventilation rate between the models.

As stated in Table-5, level 1 is excluded in this study because the ventilation rate, *Q* for all the models is calculated with the effect of podium, which has no living units on the ground floor for Model B (both CFD and WT). This study suggests that the ventilation rate is increasing to the lower levels of the building with the provision of void. However, there is the decreasing of ventilation rate for Model C with the enlargement 50% of Model's B void's size, which decreased 1.03%. Thus, this study suggests that the increasing of voids decrease the wind speed and increase wind pressure at leeward facade, as a result of venturi effect [32]. Therefore, Δp value is less different, result in less reduction of ventilation rate.

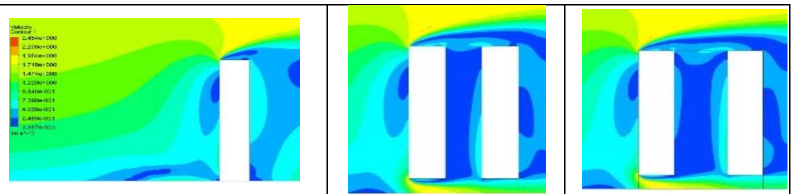
Figure-7 illustrates the comparison of air velocity distributions between Models A (without void), Model B (with void) and Model C (+50% of Model B's void).

Table-5. Comparison of ventilation rate (*Q*) of Model A (WT), Model B (WT), Model A (CFD), Model B (CFD) Model C (CFD +50% of Model B's void).

h / H	CFD					WT		
	Model A (without void**)**	**Model B** (with void)	**Different**	**Model C** (with +50% void**)**	**Different**	**Model A** (without void**)**	**Model B** (with void**)**	**Different**
0								
1	1.07	0.61	0.46	0.00	0.46	1.27	0.00	1.27
2	1.07	1.34	0.27	1.33	0.26	1.28	1.01	0.27
3	1.08	1.34	0.26	1.33	0.25	1.23	1.27	0.05
4	1.10	1.34	0.25	1.34	0.24	1.29	1.39	0.10
5	1.12	1.35	0.23	1.35	0.22	1.26	1.37	0.11
6	1.15	1.36	0.21	1.35	0.20	1.33	1.46	0.14
7	1.17	1.36	0.19	1.35	0.18	1.37	1.42	0.06
8	1.19	1.36	0.17	1.35	0.16	1.37	1.43	0.06
9	1.21	1.36	0.15	1.35	0.14	1.39	1.47	0.08
10	1.23	1.36	0.13	1.35	0.11	1.41	1.42	0.01
11	1.25	1.36	0.11	1.34	0.09	1.42	1.44	0.03
12	1.26	1.36	0.10	1.33	0.07	1.38	1.42	0.04

As illustrated in Figure-7, this study compares the result of ventilation rate for the living units that directly received 0° wind flow because these units is under the same condition of windward pressure. Therefore, the different performance of voids with different sizes can be investigated. This study reveals that the changes of void's size influenced the different velocity pattern at the leeward façade of the living units.

ARPN Journal of Engineering and Applied Sciences



Model A (without void)	Model B (with void)	Model C (+50% void)

Figure-7. Comparison of air velocity distributions between Model A (with void), Model B (with void) and Model C (+50% of Model B's void)

CONCLUSIONS

As a conclusion, this study suggests that the internal void has a potential to propose for MCMSH to enhance the natural ventilation for the building. Thus, the performance of voids has to be further investigated. It was hypothesized based on venturi effect principle, which is when the fluid passes through a constricted area, the fluid velocity increase and the fluid pressure reduce. Therefore, this pilot study's findings revealed that the decreasing of void's size reduces the wind pressure in void's area, which confirmed the venturi effect principles. With the decreasing of wind pressure in void's area, ventilation rate of the studied living units is increased. As a result, this condition caters better level of comfort for the occupants of MCMSH.

ACKNOWLEDGEMENT

The authors express great gratitude to the Ministry of Education Malaysia and the National University of Malaysia (UKM) for providing Exploratory Research Grant Scheme (ERGS/1/2013/TK07/UKM/02/6) and University/Industry Research Grant (Industri-2014-003), respectively, to fund this research.

REFERENCES

[1] Wang Y., Zhao F. Y., Kuckelkorn J., Liu D., Liu J. and Zhang J. L. 2014. Classroom energy efficiency and air environment with displacement natural ventilation in a passive public school building. Energy and Buildings. 70: 258-270.

[2] Cho J., Yoo C., and Kim Y. 2014. Viability of exterior shading devices for high-rise residential buildings: Case study for cooling energy saving and economic feasibility analysis. Energy and Buildings. 82: 771-785.

[3] Ahmad Ibrahim N. M. A. and Yusoff W. F. M. 2013. Application of solar induced ventilation prototype in a single storey building in hot and humid climate. In Conference on Affordable Quality Housing 2013, Putrajaya. 53-59.

[4] AllardF. 2002. Natural Ventilation in buildings: A design handbook. London: James & James (Science Publishers) Ltd.

[5] Awbi H. 2008. Ventilation Systems: Design and Performance. New York: Taylor & Francis.

[6] Cheung J. O. and Liu C. H. 2011. CFD simulations of natural ventilation behaviour in high-rise buildings in regular and staggered arrangements at various spacings. Energy and Building. 43(5): 1149-1158.

[7] Kim M. H., and Hwang J. H. 2009. Performance prediction of a hybrid ventilation system in an apartment house. Energy and Buildings. 41(6): 579-586.

[8] Dola K.2012. Reaching a balance: does supply meet demand?. In Housing News, Ed. Serdang: Housing Research Centre, UPM.13: 10-11.

[9] Mohamed M. F. 2011. The potential of balconies to induce wind-driven natural ventilation in single-sided ventilated high-rise apartments.

[10] Etheridge D. 2011. Natural ventilation of buildings: theory, measurement and design. John Wiley & Sons.

[11] Kurabuchi T. N. T. 2009. A two-node heat and mass transfer network model for long-term simulation of void space of high-rise apartment houses equipped with gas-red boilers. In 11th International IBPSA Conference. 434-441.

[12] Pimolsiri Prajongsan S. S. 2012. Enhancing natural ventilation, thermal comfort and energy savings in high-rise residential buildings in Bangkok through the use of ventilation shafts. Building and Environment. 50: 104-113.

[13] Sapian A. R. 2004. Possibilities of Using Void to Improve Natural Cross Ventilation in High-Rise Low-Cost Residential Building (HRLCRB). PhD, Universiti Teknologi Malaysia.

[14] Kainakis C. J. 2005. Combined thermal and natural ventilation modelling for long-term energy assessment: validation with experimental measurements. Energy and Buildings. 37: 311-323.

[15] Krishan A., Yannas S., and Szokolay S. V. 2004. Climate responsive architecture: A design handbook for energy efficient buildings. New Delhi: Tata McGraw-Hill.

[16] Siew C. C., Che-Ani A. I., Tawil N. M., Abdullah N. A. G., and Mohd-Tahir M. 2011. Classification of natural ventilation strategies in optimizing energy consumption in Malaysian office buildings. Procedia Engineering. 20: 363-371.

[17] Yusoff W. F. M., Salleh E., Adam N. M., Sapian A. R., and Sulaiman M. Y. 2010. Enhancement of stack ventilation in hot and humid climate using a combination of roof solar collector and vertical stack. Building and Environment. 45(10): 2296-2308.

[18] Allard F. and Ghiaus C. (Eds.). 2015. Natural ventilation in the urban environment: assessment and design. UK: Bath Press.

[19] Zhou C., Wang Z., Chen Q., Jiang Y. and Pei J. 2014. Design optimization and field demonstration of natural ventilation for high-rise residential buildings. Energy and Buildings. 82: 457-465.

[20] UBBL. 2013. Uniform Building By-Laws 1984 [G. N. 5178/85]. In Third Schedule (By-law 41), ed. Petaling Jaya: International Law Book Services.

[21] Ashrae S. 2013. Standard 62.1-2013 Ventilation for acceptable indoor air quality. Atlanta: Ashrae.

[22] CIBSE. 2008. CIBSE: Concise Handbook. In Guide B: Heating, ventilating, air conditioning and refrigeration, ed. London: CIBSE.

[23] Rundell M. 2002. In Macmillan English Dictionary for Advanced Learners: International Student Edition.

[24] Oxford: Word power Dictionary. In Oxford: Word power Dictionary. United Kingdom: Oxford University Press, 2012.

[25] Krebs J. 2007. Basics Design and Living. Switzerland: Birkhauser.

[26] Goody J., Chandler R., Clancy J., Dixon D. and Wooding G. 2010. Building type basics for housing. John Wiley & Sons. 17.

[27] Kotani H., Satoh R., and Yamanaka T. 2003. Natural ventilation of light well in high-rise apartment building. Energy and Buildings. 35(4): 427-434.

[28] Ismail A. M. 1996. Wind-driven natural ventilation in high-rise office buildings with special reference to the hot-humid climate of Malaysia (Doctoral dissertation, Cardiff University).

[29] Murakami S., Kato S., Ooka R. and Shiraishi Y. 2004. Design of a porous-type residential building model with low environmental load in hot and humid Asia. Energy and buildings. 36(12): 1181-1189.

[30] Hirano T., Kato S., Murakami S., Ikaga T., and Shiraishi Y. 2006. A study on a porous residential building model in hot and humid regions: Part 1-the natural ventilation performance and the cooling load reduction effect of the building model. Building and Environment. 41(1): 21-32.

[31] Sadafi N., Salleh, E., Haw L. C. and Jaafar Z. 2011. Evaluating thermal effects of internal courtyard in a tropical terrace house by computational simulation. Energy and Buildings. 43(4): 887-893.

[32] Blocken B., van Hooff T., Aanen L. and Bronsema B. 2011. Computational analysis of the performance of a venturi-shaped roof for natural ventilation: venturi-effect versus wind-blocking effect. Computers & Fluids. 48(1): 202-213.

[33] Tominaga Y., Mochida A., Yoshie R., Kataoka H., Nozu T., Yoshikawa M. and Shirasawa T. 2008. AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. Journal of wind engineering and industrial aerodynamics. 96(10): 1749-1761.

[34] Mohamed M. F., King S., Behnia M., and Prasad D. 2013. Coupled outdoor and indoor airflow prediction for buildings using Computational Fluid Dynamics (CFD). Buildings. 3(2): 399-421.

[35] Montazeri H. and Blocken B. 2013. CFD simulation of wind-induced pressure coefficients on buildings with and without balconies: validation and sensitivity analysis. Building and Environment. 60: 137-149.

[36] Mohamed M. F., King S., Behnia M. and Prasad D. 2014. The effects of balconies on the natural ventilation performance of cross-ventilated high-rise buildings. Journal of Green Building. 9(2): 145-160.