International Transaction Journal of Engineering, Management, & Applied Sciences & Technologies

http://TuEngr.com

A Review on the Impact of Building Geometry Factors of Glass Façade High-rise Buildings

Nurul Hidayah Roslan [a*] **and Mohd Rodzi Ismail** [b]

[a] *School of Housing, Building and Planning, Universiti Sains Malaysia, MALAYSIA*

ARTICLE INFO

Article history:
Received 25 August 2017
Accepted 21 November 2017
Available online
01 December 2017

Keywords:
Energy Efficient;
Thermal Comfort;
Urban heat island;
Building orientation;
Building shape;
Window opening;
Aspect ratio;
Shading devices.

ABSTRACT

Rapid urbanisation has led to the increase of population, which has caused limited space in developed cities. Consequently, a drastic demand for the construction of high-rise buildings has transpired. The trend of applying glass façade in high-rise buildings has become an issue and contributed to the increase of urban heat island phenomena and global warming. This paper reviews the impact of building geometry factors such as orientation, building shape, window opening, aspect ratio, and shading devices on building energy performance and thermal performance. The analysis of the previous studies on the influence of the building geometry factors was discussed and the best solution or optimum range of the factor was suggested. This review provides information about the most influential geometry factors on buildings to the designer at the early design stage.

1. Introduction

Rapid urbanissation has caused the change in the number of population in rural and urban areas. World Urbanization Prospects: The 2014 Revision (2015) stated that the population in urban areas was 30% in 1950, raised up to 54% in 2014 and predicted to reach 70% population in the year 2050. The tendency of people to live in the urban areas is due to a large number of job opportunities and economic growth. This increment leads to the high demand of high-rise residential and office buildings to accommodate the population.

High-rise buildings become a choice due to the less and compact area in the cities. On the other hand, application of glass façade in the construction of high-rise buildings becomes a norm or a trend in the design, especially in the developing cities. The use of glass façade will have an advantage in term of natural lighting to the occupants. However, it also becomes an issue when it comes to the application of glass facades in hot and humid climate countries.

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.

When applying a glass façade, the most important thing that needs consideration is its solar or heat reflection properties, as it absorbs, transmits, and reflects heat from solar radiation. Heat that is transmitted into buildings can cause discomfort, whereas the reflected one will contribute to urban heat island phenomena and global warming. To minimise the impact of glass façade to the occupants and environment, a proper design needs appropriate prioritisation.

Modernisation in building designs leads to the application of heating, ventilating and air-conditioning (HVAC) system, as well as artificial lighting, that contribute the most to the drastic increase in building energy consumption, and affect the thermal comfort of the building occupants. This factor is much less studied, but it is important, to maintain the building performance. The main parameters in building geometry are building orientation, window opening, window-to-wall ratio, building shape, aspect ratio and types of materials used.

The objective of this review is to analyse the impact of building geometry factors of the glass façade high-rise buildings on its energy and thermal comfort performances. The review will provide information to designer on the factors to be considered at early stage design.

2. Methodology

This review involved analysing 35 research articles that presented studies in building geometry factors and its impact on energy efficiency and thermal comfort performance for the past ten years, during 2007 to 2017. All reviewed articles are categorised based on different criteria, including the year of study, continent, country, climate, research parameters, and methodology. The first part of the review discusses the general analysis of literature, followed by the discussion on the impact of building geometry factors on building energy consumption and thermal performance.

3. General Analysis of Literature

To provide a clear understanding of the impact of building geometry in high-rise glass façade buildings, the main idea or findings are compared with the other previous studies. It begins with analysing the general studies on the impact of building geometry such as the types of building functions, orientation, window opening, glazed area, aspect ratio, building shape, shading coefficient, etc., to determine the similarities and contradictions.

Table 1 summarises the analysed articles in this review. The following sub-sections discuss the results of analysis of the studies that have been carried out according to the climate zone in which the studies took place, purposes of the studies, types of buildings involved and its research parameters.

3.1 Climate Zones of the Studies Took Place

For the purpose of this particular analysis, the Koppen-Geiger climate classification system is used. It shows that climate zone A (tropical/megathermal climate) has the most studies conducted on the building geometry with 45.7%, comprising countries like Singapore, Malaysia, Indonesia, United States and Canada. This is followed by the studies conducted in climate zone C (temperate/mesothermal climate) with 31.4%, involving Australia, Amsterdam, Japan, United States, Norway, China, Portugal, and Slovenia. Next are the studies conducted in climate zone B (semi-arid/arid) (20%), which include Chile, Iran, Libya, Austria, and United Arab Emirates. Lastly, for climate zone D (continental/microthermal) (8.6%), the studies were conducted in Sweden, Estonia, and Korea.

Table 1: Summary of the analysed articles.

Type of building	Year	Author	Continent	Country	Climate	Research Parameter								Methodology
						Ventilation	Materials	Opening	Building Shape	Orientation	Energy	Thermal comfort	Shading device	
Office	2017	Alghoul et al.	Africa	Libya	B			✓		✓	✓			Simulation/ Case study
	2017	Raji et al.	Australia Asia Europe	Sydney Singapore Amsterdam	C A C		✓	✓	✓		✓			Simulation
	2017	Wen et al.	Asia	Japan	C			✓		✓	✓			Case Study
	2016	Goia	Europe	Norway	C			✓		✓	✓			Simulation
	2016	Naamandadin et al.	Asia	Malaysia	A					✓	✓			Case Study
	2016	Rubio-Bellido et al.	Europe	Chile	B			✓	✓		✓			Simulation
	2016	Delgarm et al.	Asia	Iran	B					✓		✓		Simulation
	2016	Mangkuto et al.	Asia	Indonesia	A			✓		✓	✓			Simulation
	2016	Lau et al.	Asia	Malaysia	A		✓	✓			✓		✓	Case study/ simulation
	2015	Ma et al.	America	US	C		✓	✓			✓	✓		Simulation
	2013	Susorova et al.	America	US	C			✓	✓	✓	✓			Simulation
	2010	Su and Zhang	Asia	China	C		✓	✓		✓	✓			Simulation
	2008	AlAnz et al.	Asia	Quwait	B		✓	✓	✓		✓	✓		Simulation
Residential	2017	Shao et al.	Asia	China	C			✓		✓		✓		Simulation
	2017	Lu et al.	Asia	China	C			✓	✓	✓	✓			Simulation
	2016	Tettey et al.	Europe	Sweden	D			✓		✓	✓			Case Study
	2016	Premrov et al.	Europe	Slovenia	C				✓	✓	✓			Case Study
	2016	Jovanovic et al.	Europe	Austria	B			✓			✓			Case Study
	2016	Kim et al.	Europe	Canada	A			✓		✓	✓			Simulation
	2016	Hemsath	America	US	A					✓	✓			Case Study
	2016	Amaral et al.	Europe	Portugal	C			✓		✓		✓	✓	Case Study
	2015	Aflaki et al.	Asia	Malaysia	A	✓				✓		✓		Case Study
	2015	Tibi and Mokhtar	Asia	UAE	B		✓	✓			✓			Case Study
	2015	Hee et al.	Asia	Malaysia	A		✓	✓			✓			Case Study
	2014	Tibi & Mokhtar,	Asia	UAE	B		✓	✓		✓	✓		✓	Simulation
	2014	Chung et al.	Asia	Malaysia	A			✓		✓		✓		Case Study
	2014	Lim and Lim	Asia	Malaysia	A	✓		✓				✓		Case Study
	2013	Thalfeldt et al.	Europe	Estonia	D		✓	✓		✓	✓			Case Study
	2011	Al-Tamimi and Fadzil	Asia	Malaysia	A				✓			✓	✓	Simulation
	2011	Al-Tamimi et al.	Asia	Malaysia	A			✓		✓		✓		Case Study
	2009	Sembiring	Asia	Malaysia	A					✓		✓		Case Study
Others	2015	Loekita and Priatman	Asia	Indonesia	A		✓	✓	✓					Simulation
	2014	Asadi et al.	America	US	A				✓	✓	✓			Simulation
	2012	Choi et al.	Asia	Korea	D		✓		✓	✓	✓			Case Study
	2011	Tahmasebi et al.	Asia	Malaysia	A		✓	✓		✓	✓			Simulation

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.

3.2 Purpose of Studies

A study on building geometry factors can be for several purposes. Figure 1 illustrates the purposes of studies on geometry factors found in this review. 49% of the studies were conducted to investigate the building energy efficiency, while 23% of them show that the authors were interested in the impact of building geometry factors on indoor thermal comfort. Another 22% of the studies focus on the materials performance, whereas 6% show the interest of the researchers on building ventilation performances. Only one study is found to look into the impact of geometry on building cost.

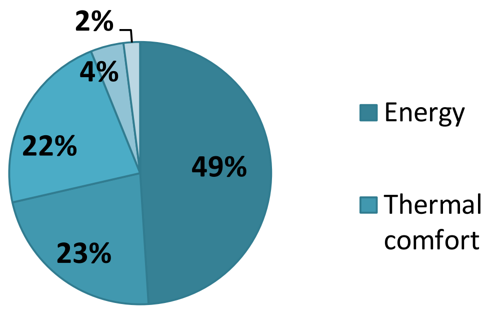


Figure 1: Research purposes found in the analysed articles.

3.3 Type of Buildings Studied

From the review, 50% of the studies are found to be conducted in residential buildings, while 36% of the studies involve office buildings. On the other hand, 14% of the studies were conducted in other types of buildings, which focused on the mixed-use buildings, its theoretical and methodology development. These are summarised in Figure 2.

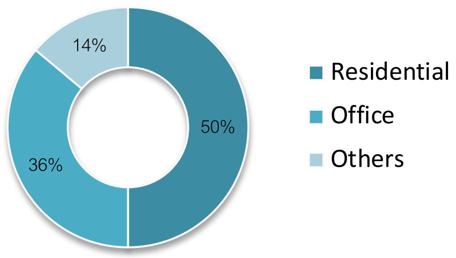


Figure 2: Types of buildings involved in the studies.

3.4 Studied Parameters

There have been numerous conducted in search of the impact of building geometry on building performance, including energy efficiency, thermal comfort, life cycle cost, ventilation, etc. Figure 3 shows the frequency of the geometry factors studied in the analysed articles. The most studied parameters are the window-to-wall ratio or window opening with 25 numbers of studies, followed by 24 numbers of studies on building orientation. Building shape has seven numbers of studies, while the aspect ratio only has two. Finally, shading devices have four numbers of studies conducted.

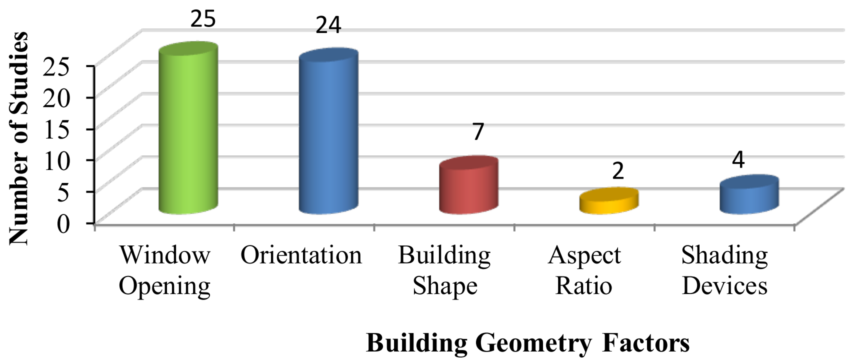


Figure 3: Number of studies on specific building geometry factors.

4. The Impact of Building Geometry on Building Energy Consumption

The number of newly constructed buildings has been rapidly increasing in the past half-century, in which the greatest increase has been observed in the number of newly constructed high-rise buildings in the past decade. Consequently, the energy consumption in the buildings has also been increasing due to the modernisation and enhancement in the building environment.

Susorova et al. (2013) stated that the demands in cooling and heating energy are influenced by the internal and external sources of heat gains and losses through facades. The examples of internal heat sources are artificial lighting, building equipment, machinery and people. Radiation from the sun, air temperature and air velocity are categorised as the external heat sources. The arrangement and the proportion of the windows contribute the most heat gain and loss due to the properties of window materials and direct exposure to solar radiation.

To date, multiple studies have been carried out in determining the performance of building energy by considering the factor of building geometry. The factors studied include window-to-wall ratio, building orientation, building shape, aspect ratio, shading devices, etc. Of all, window-to-wall ratio and building orientation have been the most studied factors.

4.1 Locality and Building Orientation

In determining the optimum building orientation performance, it is necessary for the researcher to understand the influence of the solar path on the selected research locations. According to Raji et al. (2017), the heat losses and gains in the building are influenced by solar path, and the latitude of the studied location.

In this review, few studies conducted in different locations were analysed, i.e. Sydney, Amsterdam and Singapore. For buildings in Amsterdam, South orientation becomes critical as the city is located in the upper part of the equator. On the other hand, the solar path makes North orientation becomes crucial for buildings in Sydney as it is located below the equator. Meanwhile, the location of Singapore which is near the equator makes its East-West oriented buildings become more sensitives to solar radiation.

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.

This similarity can be found in other studies conducted near the equator region such as Malaysia and Indonesia (Aflaki et al., 2016; Al-Tamimi & Fadzil, 2011; Chung et al., 2014; Lau et al., 2016; Loekita & Priatman, 2015; M. Al-Tamimi et al., 2011; Mangkuto et al., 2016; Naamandadin et al., 2016; Sembiring, 2009; Tahmasebi et al., 2011). These researchers suggested that the East-West orientation for buildings near the equator region should be avoided.

In other words, the energy consumption in buildings can be reduced by optimising its orientation. If this cannot be adopted in the design, another alternative is to optimise the window opening.

4.2 Window-to-wall Ratio and Window Orientation

Window-to-wall ratio (WWR) and window orientation (WO) play a significant role in heat losses and gains by buildings due to its direct exposure to solar radiation. In Japan, Wen et al. (2017) researched on producing maps of recommended WWR. The maps provide the designers with options to select an appropriate WWR according to Japanese climate regions. The WWR is optimised by considering the effect of carbon dioxide (CO_2) emission. This advancement of methodology helps the designer to appropriately design buildings at its early stage.

Alghoul et al. (2017) conducted a study on the influence of WWR and WO on the total energy use for heating and cooling of an office building in Tripoli, Libya. This study adopted simulation and case study approaches in providing a simple correlation for a proper façade design regarding energy consumption. The results of the study show that the cooling energy consumption increases with the increase of WWR. Besides, the heating energy consumption is found to be less than the cooling energy consumption due to the nature of climate for winter and summer within that area. More extreme ambient temperature is experienced in summer as the climate is very hot and humid. Hence, more cooling energy is required. Orientation wise, the South is more critical for all WWR conditions as additional of windows to this façade contributes to passive solar heating that lowers the heating energy consumption but a drastic increase in cooling energy occurs.

On the other hand, the optimum value of WWR is also influenced by the glazing materials used. Goia (2016) found that the optimum range of WWR in all climates falls within 30% to 45% when 0.7 W/m^2K of U-value for the glazing materials is used, except for critical ones that require WWR values out of this range. Meanwhile, Raji et al. (2017) in his research found that the WWR values for temperate, sub-tropic and tropic are between 20% to 30%, 35% to 45% and 30% to 40% respectively when the U-value of glazing materials used is 1.5 W/m^2K. The effect of glazing materials used on WWR was also studied by other researchers (Lu et al., 2017; Mangkuto et al., 2016; Su & Zhang, 2010; Tibi & Mokhtar, 2015). The relationship between these two parameters consequently affects the building energy performance.

In summary, it can be concluded that the WWR is influenced by the building orientation, window opening, as well as the reflection factor of the glazing materials.

4.3 Building Shape, Aspect Ratio and Shading Devices

There is a limited number of studies on the relationship between building shape and the application of glass façade in buildings. Nevertheless, there have been few studies on the effect of building shape on energy consumption such as the ones conducted by Asadi et al. (2014); Loekita & Priatman, (2015); Lu et al. (2017) and Premrov et al. (2016).

Also, Raji et al. (2017) studied the impact of building shape on the energy consumption in three different climates, which its results show that, the largest energy consumption occurs in sub-tropical climate while the least occurs in the tropical climate. Regarding building shape, ellipse is found to be the most optimum shape in all climates. Furthermore, the ellipse shape is found to be the most efficient shape in temperate and sub-tropical climates. As for tropical climate, the octagon is found to be the most efficient building shape. In contrast, the Y-shape is found to be the worst shape for energy efficiency in all climate conditions.

According to AlAnzi et al. (2009), the total building energy use is influenced by the relative compactness of the building. The energy consumption of building decreases when the relative compactness increases. A study on mixed-used high-rise buildings in Korea shows that the tower type buildings consume more energy in terms of electricity consumption by the residents (Choi et al., 2012). Residents feedback on the survey conducted reveals that the tower-type apartment buildings receive excessive light in summer, thus contributes to a higher energy demand for cooling purpose.

The impact of aspect ratio on building energy performance was studied by Raji et al. (2017) and Susorova et al. (2013). The results show that the aspect ratio has the most influence in the temperate climate, followed by the tropical and subtropical climates, with the efficiency of 12.8%, 8.8% and 6% respectively (Raji et al., 2017). The results also show that the optimum range of aspect ratio for Amsterdam and Singapore is between 1:1 to 3:1, while the optimum range of aspect ratio for Sydney is from 3:1 to 4:1. Susorova et al. (2013) on the other hand found that shallow rooms have the best energy performance in hot and temperate climates, while deep rooms perform the best in cold climate.

Lau et al. (2016) conducted a study on the potential of shading devices and glazing configuration in energy saving performance in high-rise buildings. They found that the egg-crate shading devices show the best performance in energy saving in hot and humid climate as compared to another type of shading devices. The application of shading devices on the East-West orientation helps in reducing the energy consumption.

From the above discussion, it can be summarised that the shape of the building, its aspect ratio and shading devices have their roles in determining the energy performance of buildings.

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.

5. The Impact of Building Geometry on Indoor Thermal Performance

The capability of indoor thermal performance is much more similar to the energy performance that has been discussed previously. The indoor thermal performance is influenced by solar transmission through windows, and solar radiation that is absorbed by building façades. There is also a limited number of studies on the thermal performance of glass façade buildings. The indoor thermal performance of buildings can be determined by assessing the indoor thermal comfort parameters and occupants perception survey. The effect of building orientation on indoor thermal condition was studied by Aflaki et al. (2016); Amaral et al. (2016); Al-Tamimi & Fadzil (2011); Sembiring (2009) and Shao et al. (2017). The criticality of building orientation depends on latitude and the solar path of where the building is located. The solar path contributes the most heat gain if the facade is directly exposed to direct sunlight. Besides building orientation, few studies were also conducted pertaining to the effect of WWR and the U-value of the glazing materials on the indoor thermal condition (Amaral et al., 2016 and Ma et al., 2015).

The indoor thermal condition is also affected by the types of shading devices used. Al-Tamimi & Fadzil (2011) found that the application of the egg-crate type of shading devices decreases the indoor ambient temperature and at the same time reduces the total number of discomfort hours due to its arrangement that prevents solar radiation from different angles.

Ventilation can have its effect on the indoor thermal condition as well. Aflaki et al. (2016) found that the single-sided ventilation in high-rise residential buildings can reduce the absorbed heat through solar radiation effectively, thus reduces heat gain into space. From the study, a better indoor thermal condition is also found to be contributed by the prevailing winds, especially for spaces located on the higher floors of the buildings.

Although the influence of building geometry on the thermal performance has been discovered by few researchers, the issue is still scarce in literature, especially in high-rise and glass façade buildings.

6. Conclusion

In the last decade, the increase in the number of high-rise buildings and application of glass façade had shown some impact on the outdoor and indoor environment. This review highlights some of the important key points with regard to energy consumption in buildings and its indoor thermal conditions. Selection and application of the appropriate building geometry factors at the early stage of the design process will help in improving the performance of buildings.

7. Acknowledgements

The authors would like to thank the Universiti Tun Hussein Onn Malaysia (UTHM) and the Ministry of Higher Education Malaysia (MOHE) for financial support which made this work possible.

8. References

Aflaki, A., Mahyuddin, N., & Baharum, M. R. (2016). The influence of single-sided ventilation towards the indoor thermal performance of high-rise residential building: A field study. *Energy and Buildings*, *126*, 146–158.

Al-Tamimi, N. A., & Fadzil, S. F. S. (2011). The potential of shading devices for temperature reduction in high-rise residential buildings in the tropics. *Procedia Engineering*, *21*, 273–282.

AlAnzi, A., Seo, D., & Krarti, M. (2009). Impact of building shape on thermal performance of office buildings in Kuwait. *Energy Conversion and Management*, *50*(3), 822–828.

Alghoul, S. K., Rijabo, H. G., & Mashena, M. E. (2017). Energy consumption in buildings: A correlation for the influence of window to wall ratio and window orientation in Tripoli, Libya. *Journal of Building Engineering*, *11*(April), 82–86.

Amaral, A. R., Rodrigues, E., Gaspar, A. R., & Gomes, Á. (2016). A thermal performance parametric study of window type, orientation, size and shadowing effect. *Sustainable Cities and Society*, *26*, 456–465.

Asadi, S., Amiri, S. S., & Mottahedi, M. (2014). On the development of multi-linear regression analysis to assess energy consumption in the early stages of building design. *Energy and Buildings*, *85*, 246–255.

Choi, I. Y., Cho, S. H., & Kim, J. T. (2012). Energy consumption characteristics of high-rise apartment buildings according to building shape and mixed-use development. *Energy and Buildings*, *46*, 123–131.

Chung, L. P., Ahmad, M. H., Ossen, D. R., Hamid, M., & Baharvand, M. (2014). The Effects of Orientations on the Room's Thermal Performance in the Tropics. *Journal of Sustainable Development*, *4*(2), 631–636.

Delgarm, N., Sajadi, B., & Delgarm, S. (2016). Multi-objective optimization of building energy performance and indoor thermal comfort: A new method using artificial bee colony (ABC). *Energy and Buildings*, *131*, 42–53.

Department of Economic and Social Affairs. (2015). *World Urbanization Prospects: The 2014 Revision*.

Goia, F. (2016). Search for the optimal window-to-wall ratio in office buildings in different European climates and the implications on total energy saving potential. *Solar Energy*, *132*, 467–492.

Hee, W. J., Alghoul, M. A., Bakhtyar, B., Elayeb, O., Shameri, M. A., Alrubaih, M. S., & Sopian, K. (2015). The role of window glazing on daylighting and energy saving in buildings. *Renewable and Sustainable Energy Reviews*, *42*, 323–343.

Hemsath, T. L. (2016). Housing orientation's effect on energy use in suburban developments. *Energy and Buildings*, *122*, 98–106.

Jovanovic, A., Pejic, P., Djoric-Veljkovic, S., Karamarkovic, J., & Djelic, M. (2014). Importance of building orientation in determining daylighting quality in student dorm rooms: Physical and simulated daylighting parameters' values compared to subjective survey results. *Energy and*

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.

Buildings, *77*, 158–170.

Kim, S., Zadeh, P. A., Staub-French, S., Froese, T., & Cavka, B. T. (2016). Assessment of the Impact of Window Size, Position and Orientation on Building Energy Load Using BIM. *Procedia Engineering*, *145*, 1424–1431.

Lau, A. K. K., Salleh, E., Lim, C. H., & Sulaiman, M. Y. (2016). Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia. *International Journal of Sustainable Built Environment*, *5*(2), 387–399.

Lim, Y.-W., & Lim, Y.-L. (2014). The Effect of Natural Ventilation and Daylighting on Occupants' Health in Malaysian Urban Housing. *30th International Plea Conference, 16-18 December 2014*, (December), 1–8.

Loekita, S., & Priatman, J. (2015). OTTV (SNI 03-6389-2011) and ETTV (BCA 2008) Calculation for Various Building's Shapes, Orientations, Envelope Building Materials: Comparison and Analysis. *Civil Engineering Dimension*, *17*(2), 108–115.

Lu, S., Tang, X., Ji, L., & Tu, D. (2017). Research on energy-saving optimization for the performance parameters of rural-building shape and envelope by trnsys-genopt in hot summer and cold winter zone of China. *Sustainability (Switzerland)*, *9*(2).

M. Al-Tamimi, N. A., Syed Fadzil, S. F., & Wan Harun, W. M. (2011). The Effects of Orientation, Ventilation, and Varied WWR on the Thermal Performance of Residential Rooms in the Tropics. *Journal of Sustainable Development*, *4*(2), 142–149.

Ma, P., Wang, L. S., & Guo, N. (2015). Maximum window-to-wall ratio of a thermally autonomous building as a function of envelope U-value and ambient temperature amplitude. *Applied Energy*, *146*, 84–91.

Mangkuto, R. A., Rohmah, M., & Asri, A. D. (2016). Design optimisation for window size, orientation, and wall reflectance with regard to various daylight metrics and lighting energy demand: A case study of buildings in the tropics. *Applied Energy*, *164*, 211–219.

Naamandadin, N. A., Sapian, A. R., & Mohd Noor, S. N. A. (2016). Site Planning and Orientation for Energy Efficiency: A Comparative Analysis on Three Office Buildings in Kuala Lumpur to Determine a Location for Building Shading Device. *Key Engineering Materials*, *700*(July), 247–255.

Premrov, M., Žegarac Leskovar, V., & Mihalič, K. (2016). Influence of the building shape on the energy performance of timber-glass buildings in different climatic conditions. *Energy*, *108*, 201–211.

Raji, B., Tenpierik, M. J., & van den Dobbelsteen, A. (2017). Early-stage design considerations for the energy-efficiency of high-rise office buildings. *Sustainability (Switzerland)*, *9*(4).

Rubio-Bellido, C., Pérez-Fargallo, A., & Pulido-Arcas, J. A. (2016). Optimization of annual energy demand in office buildings under the influence of climate change in Chile. *Energy*, *114*, 569–585.

Sembiring, M. (2009). Prediction of House Walls Temperatures Subjected to Solar Energy in Northern Malaysia, (October), 11–13.

Shao, N., Zhang, J., & Ma, L. (2017). Analysis on indoor thermal environment and optimization on design parameters of rural residence. *Journal of Building Engineering*, *12*(May), 229–238.

Su, X., & Zhang, X. (2010). Environmental performance optimization of window-wall ratio for different window type in hot summer and cold winter zone in China based on life cycle assessment. *Energy and Buildings*, *42*(2), 198–202.

Susorova, I., Tabibzadeh, M., Rahman, A., Clack, H. L., & Elnimeiri, M. (2013). The effect of geometry factors on fenestration energy performance and energy savings in office buildings. *Energy and Buildings*, *57*, 6–13.

Tahmasebi, M. M., Banihashemi, S., & Hassanabadi, M. S. (2011). Assessment of the variation impacts of window on energy consumption and carbon footprint. *Procedia Engineering*, *21*, 820–828.

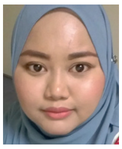
Tettey, U. Y. A., Dodoo, A., & Gustavsson, L. (2016). Primary energy implications of different design strategies for an apartment building. *Energy*, *104*, 132–148.

Thalfeldt, M., Pikas, E., Kurnitski, J., & Voll, H. (2013). Facade design principles for nearly zero energy buildings in a cold climate. *Energy and Buildings*, *67*, 309–321.

Tibi, G., & Mokhtar, A. (2014). Glass selection for high-rise residential buildings in the United Arab Emirates based on life cycle cost analysis. *Energy Procedia*, *62*, 270–279.

Tibi, G., & Mokhtar, A. (2015). Glass selection for high-rise buildings in the United Arab Emirates considering orientation and window-to-wall ratio. *Energy Procedia*, *83*, 197–206.

Wen, L., Hiyama, K., & Koganei, M. (2017). A method for creating maps of recommended window-to-wall ratios to assign appropriate default values in design performance modeling: A case study of a typical office building in Japan. *Energy and Buildings*, *145*, 304–317.



Nurul Hidayah Roslan is currently a PhD candidate at the School of Housing, Building & Planning, Universiti Sains Malaysia. She received her B.Eng. Civil Engineering from Universiti Teknologi Malaysia with Honors in 2011. She continued her Master degree also at the Universiti Teknologi Malaysia and received her M.Eng. (Material) in 2014. She has work experience as an educator in the civil engineering field which focuses on the building **structure** design and building materials. Her research interests include thermal comfort, indoor air quality, building design and building forensic.

Dr. Mohd Rodzi Ismail is an Associate Professor in the Building Technology programme at the School of Housing, Building & Planning, Universiti Sains Malaysia. He graduated with B.Sc. HBP Hons. specialising in Building Engineering, and M.Sc. in Building Technology degrees from the Universiti Sains Malaysia. He obtained his PhD from the University of Liverpool, United Kingdom. His research interests are in the areas of indoor environment, and building energy management.

Note: The original work of this article was reviewed, accepted, and orally presented at the 3rd International Conference-Workshop on Sustainable Architecture and Urban Design (ICWSAUD 2017), a joint conference with the 3rd International Conference on Engineering, Innovation and Technology (ICEIT 2017), held at Royale Ballroom at the Royale Chulan Penang Hotel, Malaysia, during 13-15th November 2017.

*Corresponding author (N.H. Roslan). Tel: +60172959340. E-mail: nurulhidayahroslan88@yahoo.com.