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The Potential of Window-Wall-Ratio Design on Cooling Energy Savings of High-Rise Green Office Buildings: The Case of Malaysia

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***Abstract*—ASEAN countries are experiencing rapid growth rate in energy consumption which raised concerns over energy supply difficulties and negative environmental impacts. High-rise office buildings in Malaysia are having high cooling energy requirements due to high solar radiation through highly or fully glazed building facades under the hot and humid climatic conditions. This study is aimed to investigate possible effects of Window-to-Wall Ratio WWR at different façade orientations on cooling energy savings through case study of a Green Building Index GBI certified high-rise green office building in Kuala Lumpur, Malaysia. IES (VE) software was used in building thermal simulations in this study. The simulation results recommend to prioritize the design of lower WWR at West facade followed by East, South and lastly North facade because the same WWR at different façade orientation has different effect on cooling energy savings. This study also suggests that reduction of WWR on West façade has the highest impact on reduction of Building Energy Index BEI, followed by East, South and lastly North facade. In regardless of orientation, lower WWR will result in lower annual cooling energy consumption and therefore higher annual cooling energy savings. This study concludes that the use of appropriate WWR design can result cooling energy savings for existing high-rise green office buildings under the GBI certification.**

Index terms -Cooling Energy Savings, Façade Orientation, High-Rise Office Buildings, Hot and Humid Climate, Window-to-Wall Ratio.

I. INTRODUCTION

World energy use is growing rapidly with concerns over supply difficulties, exhaustion of energy resources and environmental impacts [1]. Predictions by International Energy Agency show that this growing trend will continue. In the context of ASEAN countries including many developing countries such as Indonesia, Malaysia, Philippines, Thailand and so on, the energy use growing rate is very critical. This is elaborated in Table 1, showing the average annual energy demand growth rate of 2.5% (2011-2035). In the case of Malaysia, the predicted growth rate is 2.3%. The same data predicted that Malaysia will experience an increase of 29.7% of energy demand from 2011 to 2020, with average annual growth rate of 3.3% [2].

Table 1 Primary energy demand by ASEAN countries (Mtoe)

Country	1990	2011	2020	2025	2035	Average Annual Growth Rate (2011-2035)
Indonesia	89	196	252	282	358	2.5%
Malaysia	21	74	96	106	128	2.3%
Philippines	29	40	58	69	92	3.5%
Thailand	42	118	151	168	206	2.3%
Rest of ASEAN	42	119	161	178	221	2.6%
Total ASEAN	223	549	718	804	1004	2.5%

(Source: World Energy Outlook Special Report, 2013)

In the global perspective, buildings consumed up to 40% of total energy use and in the context of Malaysia, buildings consumed a total of 48% of the electricity generated in the country [3]. Referring to statistics of electricity use in Malaysia carried out by Energy Commission Malaysia in 2013, commercial buildings consumed a high percentage of 32.7% of the total energy used in Malaysia throughout the year. This is because commercial buildings in the hot and humid climate such as Malaysia are often installed with air conditioning and mechanical ventilation systems to sustain and improve indoor thermal comfort for a productive working environment. Most of the time, these systems consume the most energy among all building services [4]. From the statistics, other sectors including industrial, residential, agriculture and transport consumed 45.4% 21.4%, 0.3% and 0.2% of electricity respectively. This is shown in Table 2.

Table 2 Statistics of electricity use in Malaysia, 2013

Sector	Consumption coverage, %
Agriculture	0.3
Commercial	32.7
Industrial	45.4
Residential	21.4
Transport	0.2

(Source: Energy Commission Malaysia, 2013)

A. Hot and Humid Climate of Malaysia

Malaysia is experiencing hot and humid climatic conditions with characteristics of uniform temperature, high humidity and copious rainfall. Malaysia naturally has abundant sunshine and thus abundant solar radiation [5]. It is geographically located at latitude 3.12° N and longitude 101.55° E. Due to geographical position, the temperature typically varies from 24 °C to 34 °C and is rarely below 23 °C or above 35 °C (Weatherspark, 2016), as shown in Figure 1. The weather condition in Malaysia is such that it is a rare circumstance to witness days completely without sunshine except during the Northeast monsoon season and it is unusual to witness a whole day with a clear sky in drought season [6]. Over the course of the year, typical wind speeds in Malaysia vary from 0m/s to 5m/s (calm to gentle breeze), rarely exceeding 7m/s (moderate breeze), as shown in Figure 2.

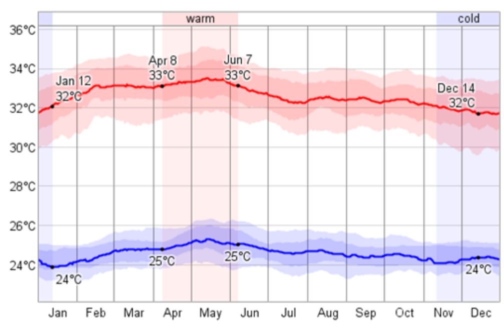

Figure 1. Daily Average Low (blue) and High (red) Temperature in Malaysia

(Source: Weatherspark, 2016)

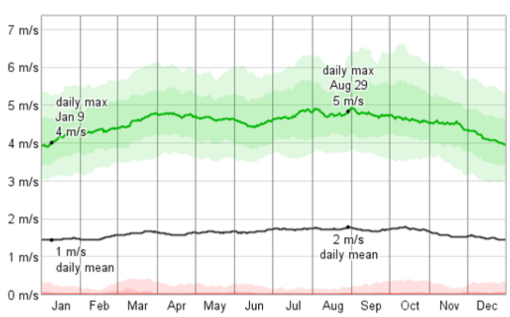

Figure 2. Daily Average Minimum (red), Maximum (green), and Average (Black) Wind Speed in Malaysia

(Source: Weatherspark, 2016)

B. The Problem of Overheating and High Cooling Energy Consumption for High-Rise Office Buildings in Malaysia

In architecture, window glazing is prestigious for its ability to present positive images such as transparency, natural brightness, modernity, freshness and indoor–outdoor interaction. Highly glazed buildings have become a worldwide design trend in modern architecture for any climate [7]. However, fully glazed facades will cause higher energy consumption and thermal discomfort due to higher solar gain [8]. From a previous study, high-rise buildings are experiencing overheating condition in hot humid climate and for a high-rise built form, vertical surfaces are the most critical to the impact of solar radiation [9]. Another study indicated that ambient temperature plays a vital role in relation to energy consumption of air conditioning system [10]. Largely glazed facades are said to be the main cause of the problem of overheating for buildings [11]. Due to high solar radiation and use of highly glazed facades causing overheating, office buildings in Malaysia consumes about 250 kWh/m2/year of energy of which about 64% is for air conditioning, 12% for lighting and 24% for general equipment [12]. Another study also showed that air conditioners are shown to be the major energy users in office buildings in Malaysia with 57% energy usage, followed by lighting of 19%, lifts and pumps of 18% and other equipment of 6% [13].

II. LITERATURE REVIEW

A previous study regarded windows as one of the most important building components, and windows are acknowledged for their positive influence on the health and well-being of building occupants. The same study noted that windows play an important role not only in providing daylight and view, but also in shaping the overall energy demand in buildings [14]. Facade configurations are predicted to be responsible for up to 45% of the building's cooling loads [15].

From the study of annual energy requirements per floor area at four climates in Turkey through four different WWR of 20%, 40% (Base case), 60% and 80%, it was found that energy requirement became higher when the glazed area increased. This study concluded that annual cooling energy requirement and annual total energy requirements of the studied office buildings with high quantities of glazing increases significantly as compared to the studied office buildings with lower glazing quantities [16].

Another recent study suggested that the building enclosure plays a relevant role in the management of the energy flows in buildings and in the exploitation of solar energy at a building scale. An optimized configuration of the façade can contribute to reduce the total energy demand of the building [17]. The same study defined the WWR as the ratio between the net glazing area and the gross exterior wall area. The results of the study concluded that optimal WWR are found in the range 35–45%, regardless the orientation, in a temperate oceanic climate. In the research on the HVAC energy consumption, a previous study used building thermal simulation software on office building with different WWR at different building orientation. The study found that the heating energy consumption, air-conditioning energy consumption and total energy consumption were gradually increased with the increase of the WWR under the same orientation [18]. Similarly, results of another recent research showed that the

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total building energy consumption increased when the WWR was also increased. In the study on the relationship of WWR and orientation on the building energy consumption, the analysis results showed that the increase of building energy consumption caused by increased WWR appeared more obvious on the East and West orientation [19].

A. Aim of Study

This study has identified the problem of high cooling energy consumption of high-rise office buildings in Malaysia caused by overheating of office spaces. This is due to high solar radiation through highly glazed building facades under hot and humid climatic conditions. However, this study also identified from previous studies that an optimum Window-to-Wall Ratio (WWR) is believed to be able in yielding significant cooling energy savings for buildings [20], [16], [17] and [18]. However, there are questions regarding the effects of WWR design on existing high-rise green office building in Malaysia since there are more and more office buildings being certified since the implementation of GBI green building rating tool in 2009.

This has set to be the point of departure of this study. Therefore, in order to address the problem of high cooling energy consumption and to address the research question, this study is aimed to investigate the potential of WWR at different façade orientations on cooling energy savings through case study of an existing GBI certified high-rise green office building in Malaysia.

III. METHODOLOGY

A. Simulation Software

After comparisons on various building thermal simulation software, Integrated Environmental Solutions Virtual Environment IES (VE) was selected as the simulation software for this study. IES (VE) provides a variety of variables for analysis as well as output graphical forms in simulation of buildings. The program provides an environment for the detailed evaluation of building and system designs, allowing them to be optimized with regard to comfort criteria and energy use [21]. Previous studies has recommended that IES (VE) energy analysis software tool is with high accuracy as from previous research analysis findings, it was concluded that there was no considerable statistical difference in the mean values between IES (VE) simulated results and measured data [22]. The Kuala Lumpur weather data from IES (VE) itself was used in all the simulations in this study.

B. The Case Study Building

In the definition of high-rise building in Malaysia, there is no national building code or regulation defining the minimum height or number of floors. However, the definition of high-rise building in this study is based on International Building Code IBC 2009 as well as National Fire Protection Association NFPA code, defining high-rise buildings as buildings with a minimum height of 75 feet (22.9 meter) above ground level. Referring to typical office buildings' floor height of approximately 3.8m in Malaysia, 22.9 m will be the height of a seven-floor office building. Therefore, seven floors is defined as the minimum number of floors acceptable as high-rise in this study.

Cap Square Tower was selected as the case study high-rise office building because it has more than 7 floors and the building facades are fully glazed with WWR of 1.0, as shown in Figure 3. This represents the modern façade design trend of office buildings in Malaysia. Furthermore, the WWR of 1.0 is suitable to be used as base case building model so that the WWR can be reduced for different building models for simulations on cooling energy consumptions. Another reason is that Cap square tower is a GBI certified green office building under the New-Construction-Non-Residential category. This helps to answer the research question and address the point of departure of this study i.e. to investigate the potential of WWR on cooling energy savings of existing GBI certified high-rise green office building in Malaysia. Cap Square Tower is located within the Cap Square development situated along JalanMunshi Abdullah, Kuala Lumpur. It consists of a 4-storey high entrance lobby with 41 floors of occupied office levels. The floor-to-floor height is 4,000 mm. Each floor boasts an efficient floor plate of approximately 1,393.55 m². with total gross floor area of 72,000 m². Cap Square Tower has a rectangular building foot print with North-South building orientation. The design utilizes perimeter of the tower as office spaces whereas the service zone is located at the center of the tower which include mechanical/ electrical rooms, toilets, pantry, and vertical transportation such as lifts and fire staircases, as shown in Figure 4.

Figure 3.Case Study Office Building

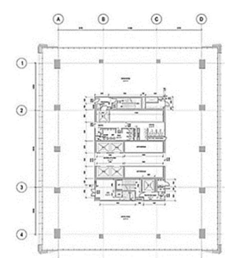


Figure 4. Case Study Office Building Typical Floor Layout

C. Construction Materials and WWR of the Case Study Building

The Cap Square Tower building model, as shown in Fig 5, was constructed in the IES (VE) software based on the actual specification and construction materials. Summary of the specification for the building model is shown in Table 3. The information was extracted from the building's website at http://www.capsquaretower.com (accessed on 23 December, 2015). Cap Square Tower has fully glazed facade facing all 4 orientations with WWR of 1.0. The building envelope comprises curtain wall system with aluminum frames and is set out on 1,160 mm grid. The curtain wall is constructed of double glazed panels with low-e glass, as detailed in Table 3,

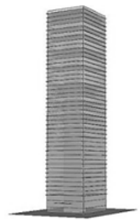


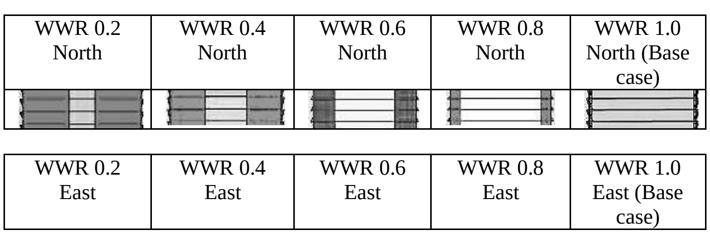
Figure 5.Case Study Office BuildingModel in IES (VE)

Table 3 Summary of Cap Square Tower specification

Description	Building Design / Material
Number of floors	- 42
Total gross floor area	- 72,000 m²
Floor-to-floor height	- 4,000 mm
Occupancy load	- 10 m²/person
Roof construction	- RC slab with water membrane insulation covered with concrete pavers
Internal ceiling and floor construction	- Raised floor system above RC slab with air plenum and suspended ceiling below slab
Window to wall ratio	- 1.0
External glazing	- Double layers of laminated low-e glazing, Shading Coefficient 0.4, U-value 3.35W/m²k
Indoor temperature	- 23°C
Air conditioning system	- Chilled water cooling with 23 VAV boxes in every floor

D. Proposed WWR for Simulations

In order to determine the proposed lowest WWR for high-rise office buildings in Malaysia, the Malaysia 1986 Uniform Building By-Laws UBBL was referred. According to 1986 UBBL (32) for commercial buildings, windows or doors opening to the exterior should have a total area of not less than 10% of the clear floor area of such room. By referring to this regulation, the minimum allowable glazing area for each façade is therefore 34 m², which is approximately 20% of façade area, with WWR of 0.2. Therefore, the proposed various WWR in this study are 0.2, 0.4, 0.6, 0.8 and 1.0 (base case WWR). There were total 20 building models being built and simulated using IES (VE) for annual building and cooling energy consumption for comparisons on possible energy savings. Each model has different WWR at one specific façade orientation while keeping the rest of facades with WWR 1.0. Images captured from the IES (VE) showing two floors of each façade presented different WWR for the 20 building models, are shown in Figure 6.



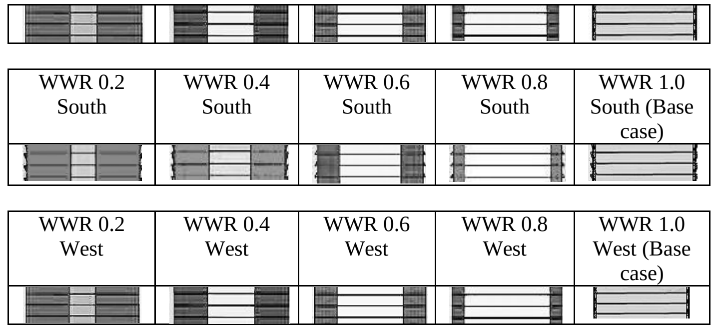


Figure 6. Proposed WWR at Different Façade Orientation for Simulation

IV. Results and discussions

A. Annual Building and Cooling Energy Consumption

The simulation results on annual building energy consumption for the 20 models are shown in Figure 7. The results indicated that among the 4 orientations, reduction of WWR at West façade has caused the most annual energy consumption reduction meanwhile reduction of WWR at North façade has caused the least annual energy consumption reduction. For example, by applying the same WWR 0.2, West façade resulted annual energy consumption of 8,300.55 MWh meanwhile North façade resulted the highest annual energy consumption of 8,425.10 MWh. East façade with WWR 0.2 however has resulted annual energy consumption of 8,369.23 MWh and South façade with WWR 0.2 resulted annual energy consumption of 8,423.39 MWh. It is noticed that reduction of WWR at West façade followed by East façade will result more annual energy consumption reduction compared to the South façade and lastly North façade. The results also showed that lower WWR has resulted lower annual energy consumption in the increasing sequence from 0.2, 0.4, 0.6, 0.8 to 1.0 regardless of the façade orientations.

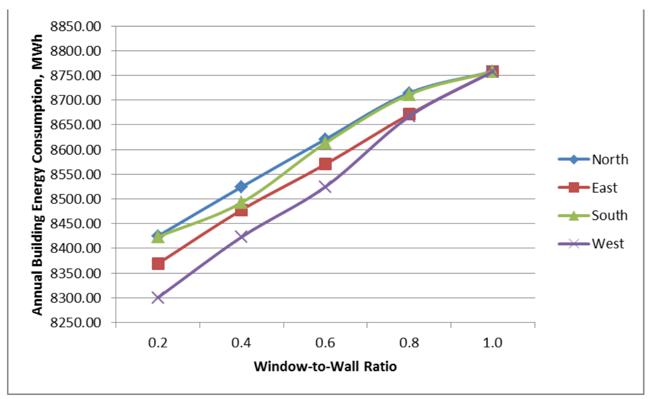


Figure 7. Annual Building Energy Consumption of Different WWR at Different Façade Orientation

For annual cooling energy consumption, Figure 8 showed that reduction of annual cooling energy consumption by reduction of WWR is more noticeable at West and East facades compared to South and North facades. By applying WWR 0.2, West façade has resulted in the lowest annual cooling energy consumption of 3,719.88 MWh and the result is 3,721.05 MWh for the East façade. Meanwhile, the WWR 0.2 has resulted higher annual cooling energy consumption at South façade at 3,753.57 MWh and North façade has the highest energy consumption at 3,755.28 MWh. The results also showed that lower WWR has resulted lower annual cooling energy consumption in the increasing sequence from 0.2, 0.4, 0.6, 0.8 to 1.0 regardless of the façade orientations. Looking at the simulated results on annual building and cooling energy consumption, the case study building used approximately 45.5% of total building energy for indoor cooling purposes.

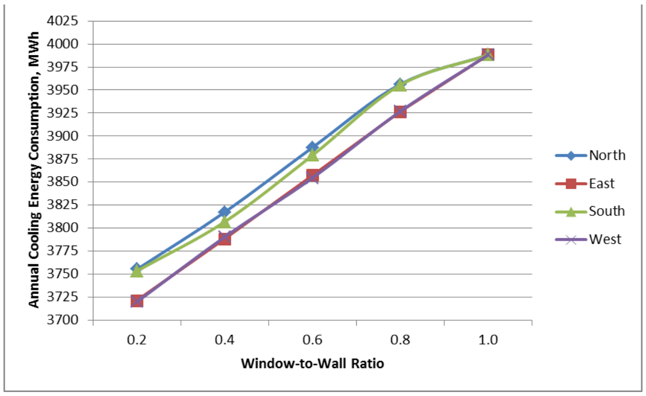


Figure 8. Annual Cooling Energy Consumption of Different WWR at Different Façade Orientation

B. Building Energy Index by Different WWR at Different Orientation

Analysis on the simulation results on the annual building energy consumption by applying different WWR at different facades indicated that WWR 0.2 at West façade has resulted in the lowest BEI at 115.3 kWh/m²/year meanwhile WWR 0.8 at both North and South facades has resulted the same BEI at 121.0 kWh/m²/year. However, table 4 indicated that the highest BEI at 121.6 kWh/m²/year was recorded with WWR 1.0 at all façade orientations which represent full glazing at all 4 facades as per the actual case study building construction. BEI was recorded to increase by applying the same WWR at different facades following sequence of West, East,South and lastly North. In regardless of façade orientation, lower WWR has resulted lower BEI in the increasing sequence from 0.2, 0.4, 0.6, 0.8 to 1.0.

Table 4 BEI of building models with different WWR and orientation

WWR	Annual Building Energy Consumption, MWh				Annual Cooling Energy Consumption, MWh				Building Energy Index BEI, kWh/m²/year			
	N	E	S	W	N	E	S	W	N	E	S	W
0.2	8425.1	8369.2	8423.4	8300.5	3755.3	3721.0	3753.6	3719.9	117.0	116.2	117.0	115.3
0.4	8524.6	8478.1	8492.7	8423.2	3817.4	3788.3	3806.9	3790.5	118.4	117.7	118.0	117.0
0.6	8620.9	8570.2	8613.1	8524.7	3887.6	3857.1	3879.2	3854.5	119.7	119.0	119.6	118.4
0.8	8714.6	8671.2	8711.7	8666.9	3956.3	3926.3	3955.4	3926.8	121.0	120.4	121.0	120.4
1.0	8758.2	8758.2	8758.2	8758.2	3988.2	3988.2	3988.2	3988.2	121.6	121.6	121.6	121.6

N = North, E = East, S = South, W = West.

C. Annual cooling energy savings by different WWR at different orientation

The simulation results on the 20 building models was analyzed in regards to the annual cooling energy savings by different WWR at different orientations. Figure 9 indicated gradual increase in the annual cooling energy savings from WWR of 1.0 to 0.8, 0.6, 0.4 and lastly 0.2 at North façade. The highest savings at 5.84% was recorded at WWR 0.2 meanwhile the lowest savings at 0.80% was recorded at WWR 0.8, with comparison to the base case situation of full façade glazing at WWR 1.0. As shown in Figure 10, reduction of WWR at South façade has resulted similar gradual cooling energy savings profile with the highest savings at 5.88% for WWR 0.2 and the lowest savings at 0.82% for WWR 0.8.

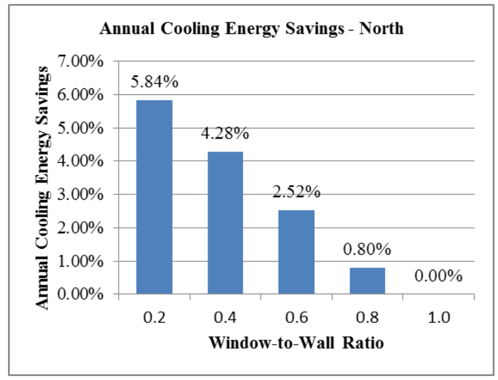


Figure 9. Annual Cooling Energy Savings by Different WWR at North Façade

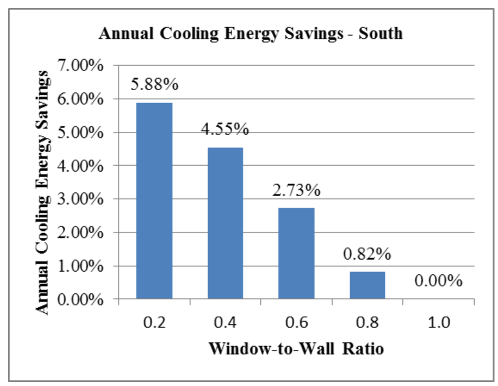


Figure 10. Annual Cooling Energy Savings by Different WWR at South Façade

With reference to the North and South facades, the reduction of WWR on the East and West facades has also resulted gradual increase in the annual cooling energy savings, as shown in Figure 11 and Figure 12. It is however noticed that WWR 0.2 has resulted the highest cooling energy savings at 6.73% for West facade, compared to the East, South and North facades at 6.70%, 5.88% and 5.84% respectively. The lowest savings at 1.55% and 1.54% with WWR 0.8 was recorded for West and East facades respectively.

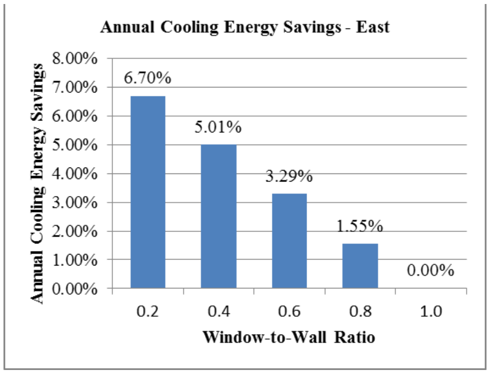


Figure 11. Annual Cooling Energy Savings by Different WWR at East Façade

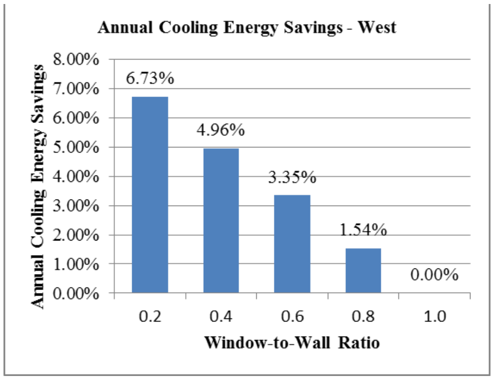


Figure 12. Annual Cooling Energy Savings by Different WWR at West Facade

V. CONCLUSION

From the analysis of the IES (VE) simulation results on the annual building and cooling energy consumption of the case study building, it can be suggested that high-rise office buildings in Malaysia use approximately 45.5% of total building energy for indoor cooling. This study also concludes that lowering of WWR will create positive effects on annual cooling energy savings, ranging between 0.80% to 6.73%, depending on the WWR and the orientations.

Major conclusions and recommendations can be made as follows:

1. It is recommended to prioritize the design of lower WWR at West facade followed by East, South and lastly North facade for maximized cooling energy savings for high-rise office buildings in Malaysia.
2. Reduction of WWR on West façade has the highest impact on BEI reduction, followed by East, South and lastly North facade.
3. Lower WWR results lower annual cooling energy consumption and therefore higher annual cooling energy savings in regardless of orientations.

In conclusion, it is recommended to prioritize and apply appropriate WWR for each specific façade orientation for high-rise office buildings in Malaysia as it is able to minimize cooling energy requirements. The use of appropriate WWR design can also result in cooling energy savings of existing high-rise green office buildings under the GBI certification. This study recommends further economic analysis on the WWR design in order to help facade designers to understand not only on thermal performances but also financial aspects for optimized high-rise office buildings design.

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