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Original Article/Research

Potential of shading devices and glazing configurations on cooling energy savings for high-rise office buildings in hot-humid climates: The case of Malaysia

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Abstract

Rapid growing of energy use has raised critical concerns over energy supply difficulties and negative environmental impacts globally and among ASEAN countries. Malaysia is experiencing a high average annual energy demand growth rate of approximately 2.3% which large portion of that energy is used by office buildings. Under the hot-humid climatic conditions in Malaysia, high-rise office buildings with large or fully glazed façades are facing a major problem of overheating due to high solar radiation through the glazed façades. This has caused high cooling energy requirements. The aim of this study is to investigate the potential of three types of shading devices on cooling energy savings when applied at different façade orientations. The aim also extends to investigations on different cooling energy savings when shading devices are applied on façade glazing with different configurations and thermal performances. This was done through a case study of a high-rise office building in Kuala Lumpur, Malaysia using IES (VE) building thermal simulation software. Twenty simulation building models were applied with different shading devices at different façade orientations and with high and low performance façade glazing. The simulation results indicate that high-rise office buildings in Malaysia use approximately 45.9% of total building energy for cooling purposes. The results also suggest that use of various shading devices on low-e double glazed façades will result between 1.0% and 3.4% annual cooling energy savings, depending on the types of shading devices and façade orientations. The estimated annual cooling energy savings increase to between 5.0% and 9.9% when the shading devices are applied to all orientations of low-e double glazed façades. The estimated annual cooling energy savings further increase to between 5.6% and 10.4% when the façade glazing is replaced by single clear glazing. This study recommends prioritizing shading devices on the East and West façades for optimized annual cooling energy savings. The simulation results show that egg-crate shadings are able to produce the highest annual cooling energy savings compared to vertical shadings and horizontal shadings. It is recommended to use shading devices on low performance glazing compared to high performance glazing since the energy savings are more significant when shading devices are used on low performance glazing. In conclusion, the use of shading devices is more effective in achieving cooling energy savings compared to the use of high performance glazing under the hot-humid climate of Malaysia.

Keywords: Cooling energy; High-rise office building; Hot-humid climate; Shading devices

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1. Introduction

Rapid growing of energy use is a major issue at the global perspective with concerns over supply difficulties, exhaustion of energy resources and environmental impacts (Pérez-Lombard et al., 2008). According to International Energy Agency, the energy use growing trend is also very critical among ASEAN countries. As shown in Table 1, an average annual energy demand growth rate of 2.5% is predicted between the year of 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 an average annual growth rate of 3.3% (Birol, 2013).

Buildings consumed up to 40% of total energy globally (Hassan et al., 2014). In the context of Malaysia, buildings consumed a total of 48% of the electricity generated in the country (Chua and Oh, 2011). According to Energy Commission Malaysia, commercial buildings consumed a high percentage of 32.7% of total energy used in the country in 2013 (Energy Commission Malaysia, 2016). This is because commercial buildings in hot-humid climates such as is found in Malaysia are often installed with air conditioning and mechanical ventilation systems to sustain and improve indoor thermal comfort. Most of the time, these systems consume the most energy among all other building services (Kwong et al., 2014). Other sectors including industrial, residential, agricultural and transport consumed 45.4%, 21.4%, 0.3% and 0.2% of electricity respectively, as shown in Table 2.

1.1. Hot-humid climate of Malaysia

Malaysia is positioned on the South China Sea. This country lies between 1° and 7° in North latitude, and 100° and 120° in East longitude (Nugroho, 2010). Malaysia is experiencing hot-humid climatic conditions with characteristics of uniform temperature, high humidity and copious rainfall. Malaysia naturally has abundant sunshine and thus abundant solar radiation throughout the year (Ministry of Science, Technology and Innovation (MOSTI), 2015). Malaysia receives an average solar radiation of 400–600 $\mathrm{MJ/m^2}$ per month (Mekhilef et al., 2012). The annual average solar radiation ($\mathrm{MJ/m^2/day}$) is shown in Fig. 1. Table 3 shows the yearly average solar radiation levels throughout different cities in Malaysia.

Due to geographical position, temperature in Malaysia typically varies from 24 °C to 34 °C and is rarely below 23 °C or above 35 °C, as shown in Fig. 2. The relative humidity varies from 54% to 96% over the course of the year and rarely drops below 44% or reaches 100% (Weatherspark, 2016). The weather conditions 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 (Mirrahimi et al., 2016). There are two types of monsoons that occur yearly, namely Northeast monsoon and Southwest monsoon. Northeast monsoon occurs between November and March. Meanwhile, the Southwest monsoon occurs between May and September. Winter-monsoon occurs during April and October and between September and December. Malaysia experiences heavy rainfall with the measurement of 2500 mm per year.

1.2. Problem of high cooling energy consumption due to overheating

Highly glazed buildings have become a worldwide design trend in modern architecture for any climate (Chown et al., 2010). In developing countries including Malaysia, huge façade glazing has been widely used to present positive architectural images such as transparency and modernity. Besides, huge façade glazing can also provide full external views. However, this causes higher energy consumption and thermal discomfort due to higher solar gain (Hien et al., 2005). From previous studies, high-rise buildings in hot-humid climate are experiencing overheating due to high solar radiation. Large glazed façades are said to be the main cause of this problem (Ling et al., 2007; Kirimtata et al., 2016). Due to the overheating condition caused by

Table 2
Statistics of electricity use in Malaysia, 2013. *Source*: Energy Commission Malaysia, 2013.

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

Table 1
Primary energy demand by ASEAN countries (Mtoe). *Source*: International Energy Agency IEA, 2013.

	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

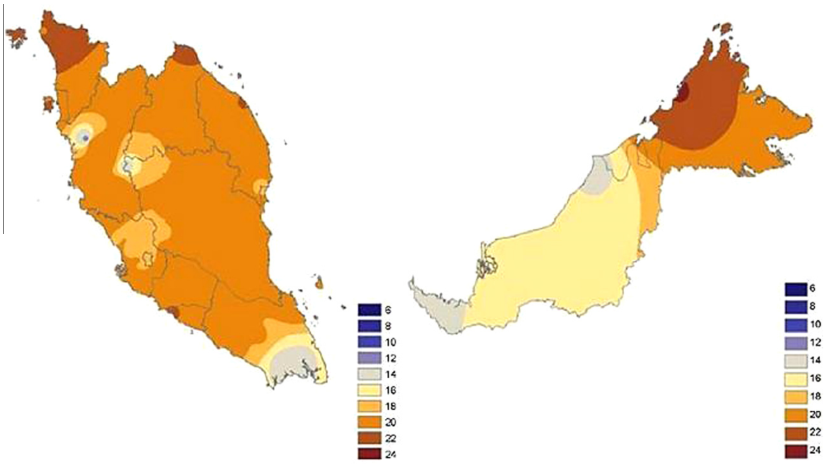


Figure 1. Annual average solar radiation (MJ/m^2/day). *Source*: Mekhilef et al., 2012.

Table 3
Yearly average solar radiations in Malaysia. *Source*: Mekhilef et al., 2012.

S/I	Region/cities	Annual average solar radiation, kW h/m^2
1	Kuching	1470
2	Bandar Baru Bangi	1487
3	Kuala Lumpur	1571
4	Petaling Jaya	1571
5	Seremban	1572
6	Kuantan	1601
7	Johor Bahru	1625
8	Senai	1629
9	Kota Baru	1705
10	Kuala Terengganu	1714
11	Ipoh	1739
12	Taiping	1768
13	George Town	1785
14	Bayan Lepas	1809
15	Kota Kinabalu	1900

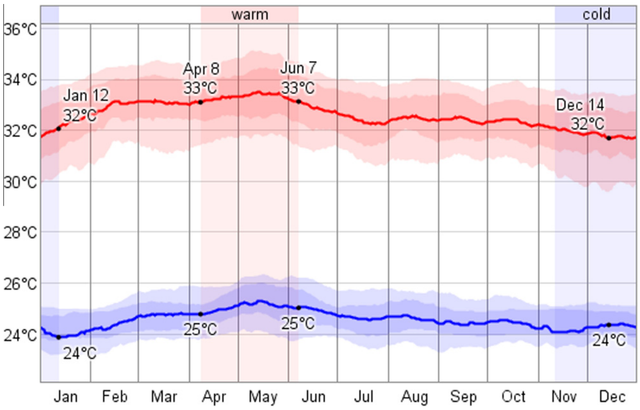


Figure 2. Daily average low (blue) and high (red) temperatures in Malaysia. *Source*: Weatherspark, 2016.

high solar radiation through largely glazed façades, office buildings in Malaysia consume between 200 and 250 kW h/m^2/year of energy of which about 64% is for air conditioning, 12% for lighting and 24% for general equipment (Chan, 2009). Another study showed that air conditioners are the major energy users in office buildings in Malaysia with 57% energy usage. This is followed by lighting 19%, lifts and pumps 18%, and other equipment 6% (Saidur, 2009).

1.3. Aim of study

This study has identified the problem of overheating as the cause of high cooling energy consumption of high-rise office buildings in Malaysia. It is noticed that this problem is due to high solar radiation through highly glazed building façades under the hot-humid climatic conditions. Building surfaces with direct exposure to the sun through windows, walls and roofs can admit heat from solar radiation. This leads to an increase in the amount of energy needed for cooling purposes. To avoid the inflow of heat, the surfaces on which the sun's rays fall must be protected. Emphasis must be given to shading devices because glazed windows are the main components which allow the penetration of incoming heat and consequently increase the risk of overheating (Datta, 2001). Previous study suggested that shading elements must be carefully integrated and considered at an early design stage as the use of shading devices is vital for façades with large, glazed portions in the sense of energy conservation in buildings (Kirimtata et al., 2016).

From the identified problems, there are always questions regarding types of appropriate shading devices to be used on specific façade orientation for maximized solar heat gain reduction. Besides, there are questions regarding different energy saving implications of shading devices on glazing with different configurations and thermal performances. These questions formed the point of departure for this study. Therefore, the aim of this study is to investigate the potential of shading devices on cooling energy savings of high-rise office buildings in Malaysia. The focus of this study is on the effect of different types of shading devices on each façade orientation, in terms of cooling energy savings. However, in order to further challenge on this issue, the focus of this study extends to the effect of various shading devices on cooling energy savings of high-rise office buildings with different façade glazing configurations and thermal performances. It is the aim of this study that the results and recommendations can be useful guidelines for façade designers not only in choosing appropriate shading devices for each specific façade orientation, but also to understand the energy saving aspect of various shading types when used on façade glazing with different configurations and thermal performances. This is useful when deciding between low performance glazing with shading devices and high performance glazing with or without shading devices.

2. Literature review

Building Energy Intensity BEI is an index used in the calculation of building energy consumption over a period of one year. According to Malaysia Standard MS 1525: 2014 Code of Practice on Energy Efficiency and Use of Renewable Energy for Non-Residential Buildings, BEI shows the total energy consumed in one year in kilowatt hours in every square meter area of the building. It is measured in kWh/m^2/year. MS 1525: 2014 recommended a BEI of not more than 180 kW h/m^2/year for non-residential buildings in Malaysia (Department of Standard Malaysia, 2014). In the case of green building rating tool in Malaysia, Green Building Index GBI was set up in 2009 as a strong operator for energy efficiency in building. Since implemented, it has positively influenced building energy efficiency practices in Malaysia (Pir Mohammadi et al., 2013). Under the GBI rating tool, buildings will be assessed and awarded based on six main design criteria. They are Energy Efficiency (EE), Indoor Environmental Quality (EQ), Sustainable Site Planning & Management (SM), Material and Resources (MR), Water Efficiency (WE) and Innovation (IN). The assessment criteria and allocated points are shown in Table 4. GBI Non-Residential New Construction rating tool requires buildings to achieve a BEI of not more than 150 kW h/m^2/year under the Energy Efficiency (EE) assessment criteria (GBI Assessment Criteria for Non-Residential New Construction (NRNC), 2016). Both MS 1525: 2014 recommendation and GBI requirements on the BEI have been used as acceptable benchmarks on energy consumption of high-rise office buildings in Malaysia.

Table 4
GBI Non-Residential New Construction assessment criteria. *Source*: Green Building Index, 2016.

S/N	Assessment criteria	Max points
1	Energy efficiency (EE)	35
2	Indoor environment quality (EQ)	21
3	Sustainable site planning & management (SM)	16
4	Materials & resources (MR)	11
5	Water efficiency (WE)	10
6	Innovation (IN)	7
	Total	100

From a previous study, external shading devices are referred to as the most effective ones comparing to internal shadings (since in this case, all the heat has already entered the space) (Offiong and Ukpoho, 2004). From that study, fixed external shading devices are feature of the architecture of the tropics. However, they are used less in temperate climates. In opposite, vertical shading devices are used extensively in temperate climates. That study also mentioned that simultaneous horizontal and vertical shading devices are used in the form of egg-crate shading devices.

In the context of Malaysia, a research paper has discussed the measurement of indoor temperature and relative humidity for an office room with three different types of shading devices namely vertical shading devices, horizontal shading devices and egg-crate shading devices. Indoor temperature and relative humidity equipment (HOBO Data Logger) was used in that study. The objective of that study was to find out a suitable shading type for achieving thermal comfort in an office building. The results indicated that egg-crate shading devices have significant impact on decreasing indoor temperature as well as discomfort hours compared with other shading types (Arifin and Denan, 2015). Another study on potential of shading devices for temperature reduction in high-rise residential buildings in Malaysia suggested that external shading devices such as overhangs, louvers, and egg-crates should be encouraged as architectural elements to protect building envelopes and occupants from solar radiation. The computer simulation results using IES (VE) showed that shading devices in both ventilated and unventilated rooms have a significant impact on improving internal thermal conditions. However, egg-crate devices are the best in reducing indoor air temperature and decreasing the number of discomfort hours because of their configuration i.e., combination of overhangs and fins. The egg-crate devices avoid solar radiation from varied sun angles (Al-Tamimia and Fadzil, 2011).

In regard to the thermal performance and energy use, a recent research studied the effects of shading devices on thermal performance of office buildings in many cities with different latitude and climatic conditions. The study showed that shading devices have a great impact on energy savings and are able to improve thermal performance of office buildings (Palmero-Marrero and Oliveira, 2010). Another previous research studied the effectiveness of shading devices on cooling energy savings for East and West windows of residential buildings in Singapore. The study showed that under hot-humid climate, 2.62–3.24% of energy cooling load can be saved by applying a simple 30 cm deep horizontal shading device to the window. When the depth of the shading devices reached 60 cm, 5.85–7.06% of the cooling load could be saved. When the depth of the shading devices reached 90 cm, the cooling load of the room was reduced by 8.27–10.13% (Wong and Li, 2007). Another previous study on a high-rise residential building in Taiwan indicated that envelope shading is the best strategy to decrease cooling energy consumption, which achieved savings of 11.3% on electric consumption (Yu et al., 2008).

A previous research carried out a study with simulations on the thermal performances of a building with design variables on building envelope and optimizations of window-shading devices (Bouchlaghem, 2000). Another research used Ombre software to evaluate the influence of the geometry of window-shading devices on the building thermal performance (Corrado et al., 2004). There were also many other studies on external façade shadings covering different climate zones using IES (VE) as building thermal simulation tools (Kim et al., 2012; Hammad and Abu-hijleh, 2010; Freewan, 2014).

In recent years, many researches were carried out to study different types of external building façade shadings and their effects on indoor air temperature, indoor thermal comfort and energy consumption. However, it is the challenge of this study to further investigate the potential of various shading devices on cooling energy requirements of high-rise office buildings in Malaysia not only in relation to different façade orientation, but also in relation to façade glazing with different configurations and thermal performances. This contributes to previous studies by providing guidance to designers in deciding between low performance façade glazing with appropriate shading devices and high performance façade glazing with or without shading devices.

3. Methodology

3.1. Simulation software

Integrated Environmental Solutions Virtual Environment IES (VE) was selected as the simulation software for this study. The selection was made based on the comparisons of various building thermal simulation software on their capabilities, user-friendly and accuracy aspects. 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 (Drury et al., 2005). Previous studies have recommended that IES (VE) is with high accuracy because 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 (Chinnayeluka, 2011). The readily available Kuala Lumpur weather data from IES (VE) itself was used in all the simulations in this study.

3.2. The case study building

There is no national building code or guidelines defining the minimum height or number of floors of high-rise buildings in Malaysia. Therefore, 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. Both codes define high-rise buildings as buildings with a minimum height of 75 feet (22.9 m) above ground level. Referring to typical office buildings' floor height of approximately 3.8 m in Malaysia, 22.9 m is the height of a seven-floor office building. Therefore, the minimum number of floors acceptable as high-rise in this study is seven.

A high-rise office building located at Jalan Munshi Abdullah, Kuala Lumpur was selected as the case study high-rise office building because it has more than 7 floors and the building façades are fully glazed with WWR of 1.0 as shown in Fig. 3. This represents the modern façade design trend of office buildings in Malaysia. Furthermore, the fully glazed façades are suitable to be used as base case building model so that this building model can be duplicated and applied with various external shading devices for simulations on cooling energy consumptions. This building consists of a 4-story high entrance lobby with 41 floors of occupied office levels. The floor-to-floor height is 4000 mm. Each floor has an efficient floor plate of 1393.55 m^2. The total building gross floor area is 72,000 m^2. It 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 Fig. 4.

3.3. Construction materials of case study building

The case study high-rise office building was constructed in the IES (VE) software based on the actual building specifications and construction materials. The model is shown in Fig. 5. Summary of the specification for the building model is shown in Table 5. The case study building has fully glazed façades facing all 4 orientations. The building envelope comprises curtain wall system with aluminum frames and is set out on 1160 mm grid. The curtain wall is constructed of double glazed panels with low-e glass.

Figure 3. Case study building.

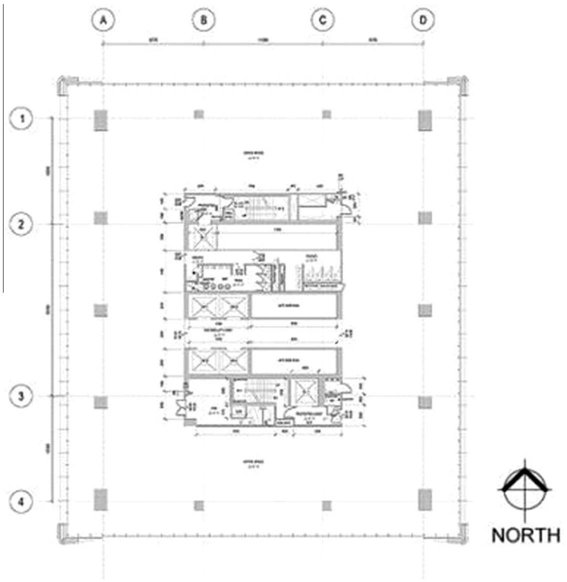


Figure 4. Case study building typical floor layout.

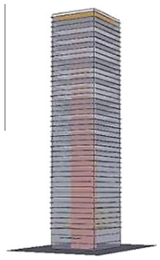


Figure 5. Case study building model constructed in IES (VE).

3.4. Types of shading devices for simulations

Due to geographical location, most of office buildings in Malaysia are facing problem of how to prevent direct sun light especially from East and West. This part of study involved simulations of three types of shading devices namely horizontal shading, vertical shading and egg-crate shading. In order to investigate the effects of these shading devices on each façade orientation in regard to cooling energy savings, the three types of shading devices were applied on North, East, South and West façades separately for simulations of annual building and cooling energy consumption. The width of the shading devices was fixed at 600 mm as recommended by many studies conducted in the tropics with considerations on day lighting, esthetic and the view angle requirements from the internal spaces (Al-Tamimia and Fadzil, 2011; Liping and Hien, 2007). There were total 13 simulations carried out for this purpose. The different types of shading devices are shown in Fig. 6.

3.5. Types of façade glazing configurations for simulations

As mentioned earlier, the focus of this study is on the effect of different types of shading devices on each façade orientation in terms of cooling energy savings. However, the focus extends to further challenge this issue with reference to different façade glazing configurations i.e. high performance and low performance façade glazing. In this part of simulation, the high performance double glazed façades of the base case building model were replaced by low performance 6 mm single clear glazing with Shading Coefficient 0.9 and U-value 6.38 W/m^2 k. There were 6 simulations carried out by applying horizontal shadings, vertical shadings and egg-crate shadings on the façades of building models with double glazing and single glazing for comparisons on cooling energy savings. With this, we are able to understand the energy saving effects of various shading types on different façade glazing types.

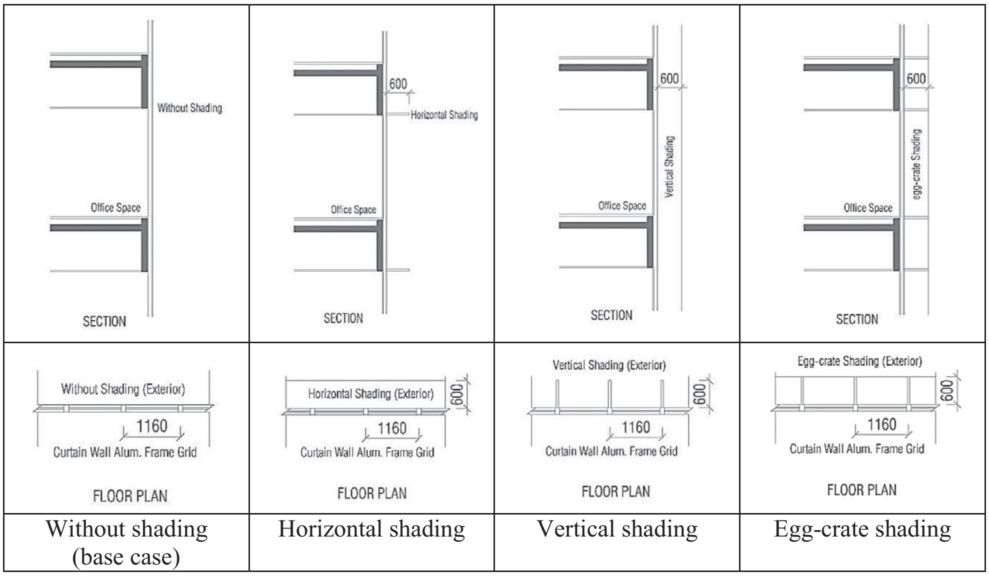
4. Results and discussion

4.1. Monthly building and cooling energy consumption of base case model with double glazing

The simulation results on monthly building energy consumption of the base case model are shown in Fig. 7. The results indicated the lowest monthly energy consumption of 675.59 MW h in February. On the contrary, the results indicated the highest monthly building energy consumption of 787.47 MW h in July. The difference between the lowest and the highest monthly energy consumptions is

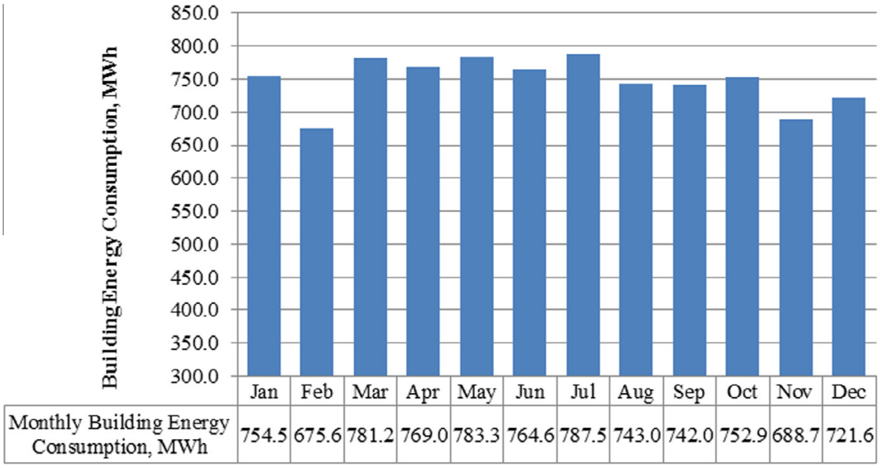
Table 5
Summary of case study building specifications.

Description	Building design/material
Number of floors	42
Total gross floor area	72,000 m^2
Floor-to-floor height	4000 mm
Occupancy load	10 m^2/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 3.35 W/m^2 k
Indoor temperature	23 °C
Air conditioning system	Chilled water cooling with 23 VAV boxes in every floor
Lighting system	400 LUX – Public Area, 400 LUX – Ground floor, 300 LUX – Corridor, 200 LUX – Staircases, 400 LUX – Lift lobbies, 100 LUX – Car park, 250 LUX – Lift, 400 LUX – Office Area



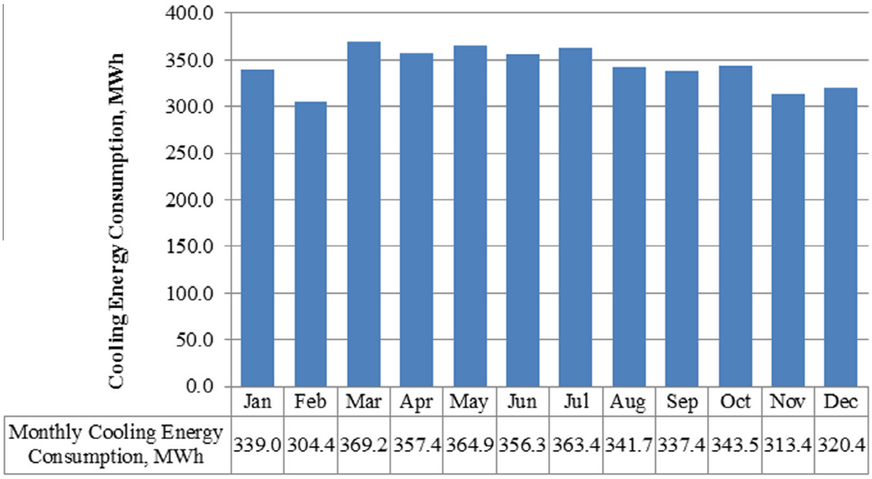
Without shading (base case) | Horizontal shading | Vertical shading | Egg-crate shading

Figure 6. Types of shading devices for energy simulations.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Building Energy Consumption, MWh	754.5	675.6	781.2	769.0	783.3	764.6	787.5	743.0	742.0	752.9	688.7	721.6

Figure 7. Monthly building energy consumption of base case model.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Cooling Energy Consumption, MWh	339.0	304.4	369.2	357.4	364.9	356.3	363.4	341.7	337.4	343.5	313.4	320.4

Figure 8. Monthly cooling energy consumption of base case model.

111.88 MW h. As shown in Fig. 8, the lowest monthly cooling energy consumption of 304.43 MW h was shown in February too. Meanwhile, the highest monthly cooling energy consumption was shown in May with 364.91 MW h. Simulation results indicated difference of 60.48 MW h between the lowest and highest monthly cooling energy consumption. From the simulation results of annual building energy and annual cooling energy consumption of 8963.89 MW h and 4111.16 MW h respectively, 45.9% of building energy was used for cooling purposes annually.

4.2. Annual building energy consumption, annual cooling energy consumption and BEI by different shading devices at different façade orientation with double glazing

From the analysis of the simulated results, base case building model without any shading devices resulted an annual building energy consumption of 8963.9 MW h with BEI 124.5 kW h/m^2/year. Horizontal shadings on the West façade resulted in the lowest annual building energy consumption of 8836.9 MW h with BEI 122.7 kW h/m^2/year. Meanwhile, applying the same shading devices on the South façade resulted in the highest annual building energy consumption of 8893.2 MW h with BEI 123.5 kW h/m^2/year. Application of vertical shadings on the West façade resulted in the lowest annual building energy consumption of 8793.3 MW h with BEI 122.1 kW h/m^2/year. Meanwhile, application of such devices on the North façade resulted in the highest annual building energy consumption of 8858.6 MW h with BEI 123.0 kW h/m^2/year. When both horizontal and vertical shading devices were combined as egg-crate shading devices, application of such devices on the West façade resulted in the lowest annual building energy consumption of 8701.7 MW h with BEI 120.9 kW h/m^2/year. Meanwhile, application of the same devices on the South façade resulted in the highest annual building energy consumption of 8805.6 MW h with BEI 122.3 kW h/m^2/year. As shown in Table 6, building model without any shading devices resulted in an annual cooling energy consumption of 4111.2 MW h. Horizontal shadings on the West façade resulted in the lowest annual cooling energy consumption of 4052.2 MW h. Meanwhile, applying the same shading devices on the North façade resulted in the highest annual cooling energy consumption of 4069.8 MW h. Application of vertical shadings on the East façade resulted in the lowest annual cooling energy consumption of 4014.3 MW h. Meanwhile, application of such devices on the North façade resulted in the highest annual cooling energy consumption of 4039.5 MW h. When both horizontal and vertical shading devices were combined as egg-crate shading devices, application of such devices on the West façade resulted in the lowest annual cooling energy consumption of 3972.1 MW h. Meanwhile, application of the same devices on the South façade resulted in the highest annual cooling energy consumption of 4006.0 MW h (Fig. 9).

Table 6
Annual building energy consumption, cooling energy consumption and BEI by different shading devices at different façade orientations.

Type of shading	Annual building energy consumption, MW h				Annual cooling energy consumption, MW h				Building energy intensity BEI, kW h/m^2/year			
	N	E	S	W	N	E	S	W	N	E	S	W
No Shading	8963.9	8963.9	8963.9	8963.9	4111.2	4111.2	4111.2	4111.2	124.5	124.5	124.5	124.5
Horizontal	8872.9	8893.1	8893.2	8836.9	4069.8	4052.4	4068.8	4052.2	123.2	123.5	123.5	122.7
Vertical	8858.6	8840.6	8843.1	8793.3	4039.5	4014.3	4031.0	4023.1	123.0	122.8	122.8	122.1
Egg-crate	8790.2	8781.6	8805.6	8701.7	4005.7	3975.4	4006.0	3972.1	122.1	122.0	122.3	120.9

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

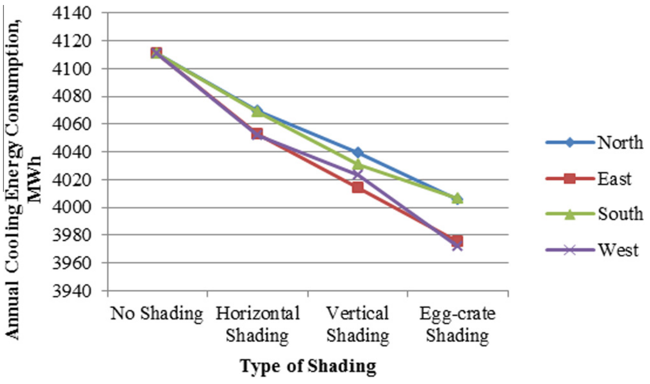


Figure 9. Annual cooling energy consumption by different shading devices at different façade orientations – double glazing.

4.3. Annual cooling energy savings by different shading devices at different façade orientation with double glazing

The simulation results of the 13 building models with different types of shading devices at different façade orientation were analyzed in regard to the annual cooling energy savings. Fig. 10 indicated egg-crate as the best shading type for optimum cooling energy savings. This is followed by vertical shading and lastly horizontal shading. The highest savings of 3.4% was estimated by applying egg-crate shadings on the West façade; 3.3% savings on the East façade; and 2.6% savings on the North and South façades. Use of horizontal shading devices resulted in annual energy savings of 1.4% on East and West façades, and 1.0% on North and South façades. Vertical shading devices resulted in annual cooling energy savings between 1.7% and 2.4% at different façade orientations, as shown in Fig. 10. As shown in the same Fig. 10, egg-crate shading devices resulted in 3.4% of energy savings on the West façade and 3.3% energy savings on the East façade comparing to only 2.6% energy savings on the North and South façades. Similarly, vertical shadings resulted in higher energy savings of 2.4% on the East façade and 2.1% energy savings on the West façade comparing to only 1.9% and 1.7% energy savings on the South and North façades respectively. Higher energy savings of 1.4% was estimated by having horizontal shading devices on West and East façades comparing to only 1.0% of energy savings on North and South façades.

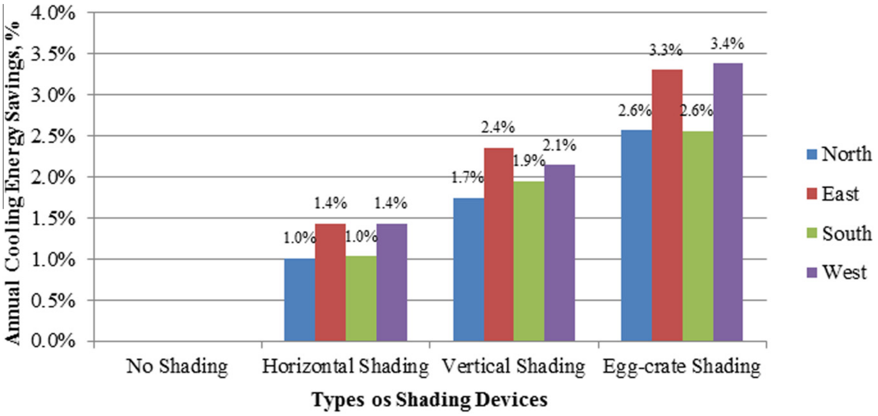
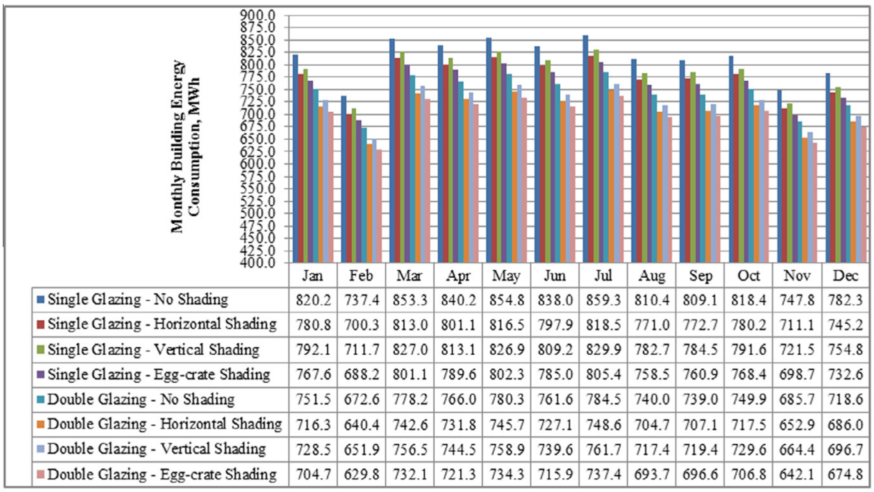


Figure 10. Annual cooling energy savings by different types of shading devices.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Single Glazing - No Shading	820.2	737.4	853.3	840.2	854.8	838.0	859.3	810.4	809.1	818.4	747.8	782.3
■ Single Glazing - Horizontal Shading	780.8	700.3	813.0	801.1	816.5	797.9	818.5	771.0	772.7	780.2	711.1	745.2
■ Single Glazing - Vertical Shading	792.1	711.7	827.0	813.1	826.9	809.2	829.9	782.7	784.5	791.6	721.5	754.8
■ Single Glazing - Egg-crate Shading	767.6	688.2	801.1	789.6	802.3	785.0	805.4	758.5	760.9	768.4	698.7	732.6
■ Double Glazing - No Shading	751.5	672.6	778.2	766.0	780.3	761.6	784.5	740.0	739.0	749.9	685.7	718.6
■ Double Glazing - Horizontal Shading	716.3	640.4	742.6	731.8	745.7	727.1	748.6	704.7	707.1	717.5	652.9	686.0
■ Double Glazing - Vertical Shading	728.5	651.9	756.5	744.5	758.9	739.6	761.7	717.4	719.4	729.6	664.4	696.7
■ Double Glazing - Egg-crate Shading	704.7	629.8	732.1	721.3	734.3	715.9	737.4	693.7	696.6	706.8	642.1	674.8

Figure 11. Monthly building energy consumption by different shading devices on all façades – single and double glazing.

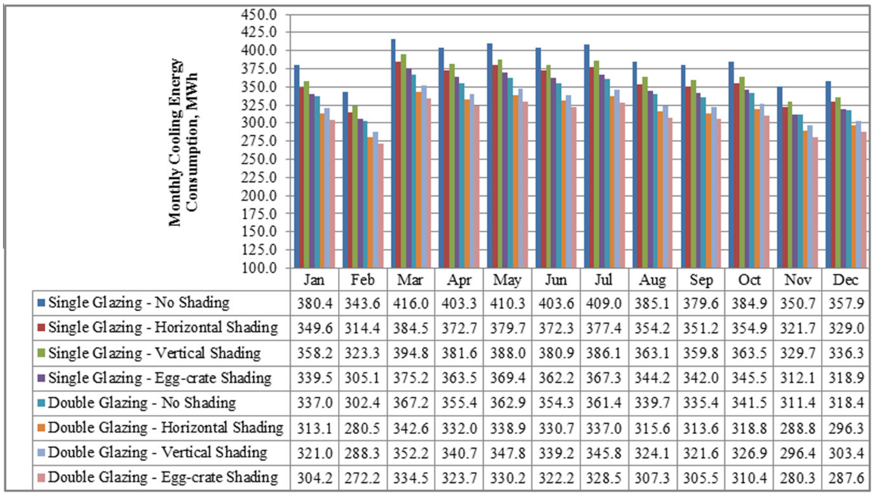
4.4. Comparisons of monthly building energy consumption, monthly cooling energy consumption, BEI and annual cooling energy savings by different shading devices at all façades with double and single glazing

The simulations and analysis above focused on cooling energy savings by different shading types on different façade orientations with double glazing. The following simulations and analysis extended the focus to comparisons of the cooling energy savings by different shading types on all façades but with different glazing configurations i.e. high performance double low-e glazing and single 6 mm clear glazing. From the simulated results shown in Figs. 11 and 12, egg-crate shadings resulted in the lowest monthly building and cooling energy consumption in every month of the year compared to horizontal and vertical shadings. This is for both cases of double glazing and single glazing. The results showed February as the month with the lowest building and cooling energy consumption while high energy consumption was shown between March and July. The BEI of the base case building model with double glazing and without any shading was reduced from 124.5 kW h/m^2/year to 116.5 kWh/m^2/year when egg-crate shadings were applied to all the façades. This resulted in annual cooling energy savings of 9.9% as shown in Table 7. The use of horizontal shadings however reduced BEI to 118.3 kW h/m^2/year with annual cooling energy savings of 7.4%. Vertical shadings reduced BEI to 120.4 kW h/m^2/year with annual cooling energy savings of 5.0%. When single 6 mm clear glazing was used to replace the double glazing without any shading, BEI was increased from 124.5 kW h/m^2/year to 135.7 kW h/m^2/year. The BEI was however reduced to 127.2 kW h/m^2/year with annual cooling energy savings of 10.4% when egg-crate shadings were applied to all the façades. The use of horizontal shadings reduced BEI to 129.3 kW h/m^2/year with annual cooling energy savings of 7.8%. Vertical shadings reduced BEI to 131.2 kW h/m^2/year with annual cooling energy savings of 5.6%.

5. Discussion

The simulated annual building energy consumption of 8963.89 MW h for the base case building model indicated a BEI of 124.5 kW h/m^2/year. This is meeting the MS 1525: 2014 recommended BEI benchmark of not more than 180 kW h/m^2/year for non-residential buildings in Malaysia, as well as the GBI BEI requirements of not more than 150 kW h/m^2/year. The simulated BEI is considered low compared to an average BEI of 200–250 kW h/m^2/year for office buildings with low glazing specifications in Malaysia (Chan, 2009). This is most probably due to the use of high performance double glazing with low-e coatings which allow penetration of visible light of the solar spectrum and block the other wavelengths that are generally responsible for solar heat gains (Robinson and Hutchins, 1994). However, the BEI was increased to 135.7 kW h/m^2/year when single glazing was used. This is due to the low specification of the 6 mm single clear glazing without any low-e coating and with high U-value of 6.38 W/m^2 k.

When different types of shading devices were added to the base case building model, it was found that different types of shading devices resulted in different cooling energy requirements although they were placed at the same façade orientation. Use of same shading devices on different façade orientations also resulted in different amounts of annual cooling energy savings. It is noticed that application of all the three types of shading devices on West and East façades in general resulted in higher annual cooling energy savings compared to North and South façades. This is because buildings in Malaysia receive higher solar radiation from Eastern and Western sun during morning and evening due to the geographical position of the country (Al-Tamimia et al., 2011). Another reason is due to the rectangular shape of the building with a North–South orientation. This caused the effect of shading devices on BEI and energy savings to be more significant as these two façades have larger areas exposed to direct sun light and solar radiation. The simulation results indicated that



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
■ Single Glazing - No Shading	380.4	343.6	416.0	403.3	410.3	403.6	409.0	385.1	379.6	384.9	350.7	357.9
■ Single Glazing - Horizontal Shading	349.6	314.4	384.5	372.7	379.7	372.3	377.4	354.2	351.2	354.9	321.7	329.0
■ Single Glazing - Vertical Shading	358.2	323.3	394.8	381.6	388.0	380.9	386.1	363.1	359.8	363.5	329.7	336.3
■ Single Glazing - Egg-crate Shading	339.5	305.1	375.2	363.5	369.4	362.2	367.3	344.2	342.0	345.5	312.1	318.9
■ Double Glazing - No Shading	337.0	302.4	367.2	355.4	362.9	354.3	361.4	339.7	335.4	341.5	311.4	318.4
■ Double Glazing - Horizontal Shading	313.1	280.5	342.6	332.0	338.9	330.7	337.0	315.6	313.6	318.8	288.8	296.3
■ Double Glazing - Vertical Shading	321.0	288.3	352.2	340.7	347.8	339.2	345.8	324.1	321.6	326.9	296.4	303.4
■ Double Glazing - Egg-crate Shading	304.2	272.2	334.5	323.7	330.2	322.2	328.5	307.3	305.5	310.4	280.3	287.6

Figure 12. Monthly cooling energy consumption by different shading devices on all façades – single and double glazing.

Table 7
Annual building energy consumption, annual cooling energy consumption, BEI and annual cooling energy savings by different shading devices at all façades with single and double glazing.

Energy savings	No shading		Horizontal shading		Vertical shading		Egg-crate shading	
	Single glazing	Double glazing	Single glazing	Double glazing	Single glazing	Double glazing	Single glazing	Double glazing
Annual building energy consumption, MW h	9771.3	8963.9	9308.3	8520.7	9445.0	8668.9	9158.5	8389.4
Annual cooling energy consumption, MW h	4624.2	4111.2	4261.7	3807.9	4365.4	3907.3	4145.0	3706.5
Building energy intensity, BEI	135.7	124.5	129.3	118.3	131.2	120.4	127.2	116.5
Annual cooling energy savings, MW h	0	0	362.5	303.3	258.9	203.9	479.2	405.0
Annual cooling energy savings, %	0.0%	0.0%	7.8%	7.4%	5.6%	5.0%	10.4%	9.9%

egg-crate shadings resulted in lower annual cooling energy consumption compared to vertical and horizontal shadings. The simulated annual cooling energy savings of not more than 3.4% is not significant. This is due to the high performance double glazing with low-e coatings used by the case study building, which minimized solar heat radiation to internal spaces (Robinson and Hutchins, 1994). Use of any types of shadings on double glazing resulted in lower annual building and cooling energy requirements compared to the same type of shadings used on single glazing. However, it is important to note that the use of any types of shadings on single glazing resulted in a higher percentage of annual cooling energy savings compared to the same type of shadings used on double glazing.

From the analysis of the simulation results involved different shading devices at different façade orientations and different glazing configurations, selection of appropriate shading types for specific façade orientation can be prioritized. The impact of different shading devices and different glazing configurations on cooling energy savings can also be analyzed. The analysis of the simulated results produced conclusions and recommendations that enabled the achievement of the aim of this study i.e. to help façade designers not only in choosing appropriate shading devices for each specific façade orientation, but also to understand the energy saving aspect of various shading types when used on façade glazing with different configurations and thermal performances.

6. Conclusions and recommendations

From the analysis of the IES (VE) simulation results on annual building and cooling energy consumption of the case study building, it can be suggested that high rise office buildings in Malaysia use approximately 45.9% of total building energy for cooling purposes. This study also suggests that use of various shading devices on different façade orientations with low-e double glazing will result in annual cooling energy savings, ranging from 1.0% to 3.4%. The annual cooling energy savings are expected to increase to between 5.0% and 9.9% if the shading devices are applied to all façades of the same low-e double glazing. However, it is important to note that the annual cooling energy savings are expected to be further increased to between 5.6% and 10.4% when the shading devices are applied to all façades with single clear glazing.

Major conclusions and recommendations of this study can be made as below:

1. It is recommended to apply shading devices on façades of high-rise office buildings in Malaysia for cooling energy savings.
2. Egg-crate shading devices are able to result in higher annual cooling energy savings compared to vertical shading and horizontal shading under hot-humid climates.

3. Applying shading devices on the West and East façades will result in higher annual cooling energy savings compared to North and South façades under hot-humid climates.
4. Applying shading devices on low performance single clear glazing will result in higher annual cooling energy savings compared to high performance low-e double glazing.

In order to achieve the aims of this study, it is recommended that façade designers prioritize and apply appropriate types of shading devices on specific façade orientation on high-rise office buildings in Malaysia for maximized cooling energy savings. It is also recommended that façade designers consider the different cooling energy saving implications when shading devices are applied on glazing with different configurations and thermal performances. This study provides guidance to façade designers when deciding between low performance glazing with shading devices and high performance glazing with or without shading devices for possible cooling energy savings. This study recommends the use of shading devices on low performance glazing compared to high performance glazing since the energy savings are more significant on low performance glazing. In conclusion, shading devices are more effective in achieving cooling energy savings compared to the use of high performance glazing under the hot-humid climate in Malaysia. This study recommends further economic analysis of various types of shading devices and façade glazing with various thermal performances. This will help façade designers to prioritize between financial aspects and thermal performance of façade materials for high-rise office buildings in Malaysia.

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