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Impact of Building Envelope Modification on Energy Performance of High-Rise Apartments in Kuala Lumpur, Malaysia

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ABSTRACT

In residential buildings, providing comfortable living environment for building occupants is a major challenge for architects, engineers and those who involved in the building industry. It is reported that considerable energy is consumed to provide and maintain acceptable indoor conditions for thermal comfort in residential buildings in hot-humid climate. The observable increase in energy consumption is chiefly resulting from the growing use of air conditioning system. There are various energy conservation measures which can be applied to reduce energy consumption and among these measures are passive envelope design measures. This paper addresses the energy performance of selected high-rise apartments in Kuala Lumpur. Energy Plus software is utilized in measuring the performance because of its availability, validity and accuracy. Possible energy savings due to passive envelope design measures integration are investigated. This includes investigating the effect of thermal insulation and glazing type on potential energy savings.

1. Introduction

The rapid economic development and high population densities of many Southeast Asian Countries have created a number of cities with high density of population. Malaysia experienced an economic boost in the late 1980s. The economical rapid development creates new types of professions, which has attracted migration by the rural population to the city. The migration caused a dramatic increase in the urban population. The urban population explosion, however, has caused a housing shortage, with the cities having become overcrowded. As a result, the housing construction sector has experienced rapid development since the late 1980s and the

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development of urban areas, particularly in Kula Lumpur, has been drastically increased. Malaysian government planned to provide new places for city residents who work in Kuala Lumpur with decent living conditions (Hassan, 2005). Due to government effort, the number of residential units in urban areas has increased from 827,100 units in 1980 to 2,071,100 units in 1991. New building construction materials and methods have been introduced to build affordable and mass housing units. Terraced housing and lately high-rise apartment buildings are the most typical of the modern housing industry built based on modern construction techniques (Hassan, 2002)

Engineering has great impact on modern architecture, preceded by the Industrial Revolution. The term 'Industrial Revolution' itself defined as 'engineering' influence in architecture (Hassan, 2009). International style abandoned the traditional and culture factor in residential buildings design and popularized application of new modern materials (Hassan & Bakhalh, 2013). Residential buildings are currently constructed with highly glazed façade and thermally lightweight buildings which are unsuitable to the local hot and humid climate. This is chiefly obvious in urban areas where land is limited while population is high. As Malaysia is located in the tropics, these modern buildings are exposed to the full impact of the external temperatures and global solar radiation, which affects the occupants comfort in a negative way. Buildings are overheated during the day due to solar heat gain through the building envelope and radiant solar penetration through windows (Rajapaksha et al., 2003). It is found that many of these buildings have not been designed and operated efficiently, contributing to an overall poor thermal performance of the buildings envelope.

Poor passive thermal design in building construction causes an increase in building cooling or heating load. It is found that almost 68% of the energy is used for Heating, Ventilating and Air Conditioning Systems (HVACs). It leads to the problem of inefficient use of energy. Passive design is the building design which does not depend only on mechanical cooling or heating but it utilizes the natural resources such as winds, sunlight and sun path to gain thermal comfort. One of passive design measures is the use of vertical and horizontal shading devices which can play an active role in curbing the extent of sunlight penetration inside the house (Hassan & Arab, 2012). The basic principle of passive design is to acquire sustainable use of natural inputs from surrounding environment. This means that passive design approach applies only from available surrounding resources, which are sunlight, wind and air flow to gain thermal comfort level to the indoor temperature (Hassan & Ramli, 2010).

Thus, new high-rise residential building became more dependent on artificial means to provide comfortable thermal environment at high energy consumption (Rickwood et al., 2008, Cheung et al., 2005).The increase in energy consumption by the residential sector is mainly because of the growing demand for air-conditioning systems to provide thermal comfort for building's occupants. In Malaysia, 45% of the average household electricity is consumed by air conditioners to create acceptable indoor environment (CETDEM, 2006). This high energy consumption is mostly related to poor thermal performance of building envelope (Manioglu & Yilmaz, 2008).

Internationally, energy consumption of the residential sector accounts for 16–50% of that consumed by all sectors, and it averages approximately 30% worldwide. However, this percentage was 19% in Malaysian residential buildings as shown in Figure 1 (Saidur et al., 2007). Residential and commercial sectors contributed about 12.8% of total energy demand in 2012. These both sectors are the third largest energy demand among other sectors and this number will be increasing in future based on current needs in Malaysia (Ponniran et al, 2012). Malaysian buildings are consuming about 70% of energy for cooling the indoor environment (Abdul Rahman & Ismail, 2008). However, it is reported that more than 40% of the energy consumed by Malaysian buildings can be reduced if energy efficiency is practiced and sustainable technologies are applied to building envelope (Azni Zain, 2008).

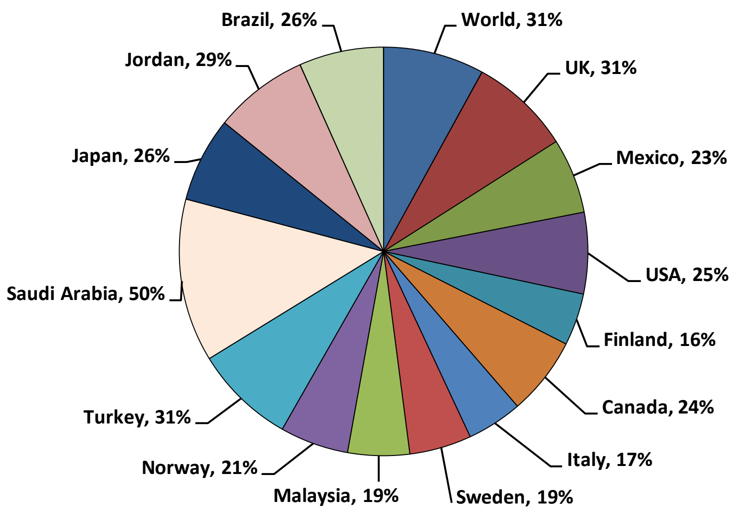

Figure 1: Worldwide residential energy consumption (Saidur, et al., 2007)

The energy consumption in buildings is normally given in terms of the Building Energy Index BEI. The South East Asian Average BEI is 233 kWh/m^2/year whereas the Malaysian average is 269kWh/m^2/yr, whereby 64% is for air conditioning, 12% lighting and 24% general equipment (Azni Zain, 2008). However, the level for low energy buildings recommended by Green Building Index GBI is between 90-150 kWh/m^2/year (MS_1525, 2007). It can be concluded that Malaysia has a strong need and great potential to apply energy efficient strategies to reduce energy consumption in buildings. Therefore, buildings, energy and the environment have become some of the key issues facing the building professions (Azni Zain, 2008). With the

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increasing population and living standards, energy issue is becoming a key issue today because of a possible energy shortage in the future (Yilmaz, 2007).

Several studies were reviewed to highlight the role of various properties of building envelope components on building energy performance and tested the different options to improve indoor environment in residential buildings in hot humid climate in South Asian countries. There are many research studies conducted in some tropical hot and humid climates such as in Taiwan, Singapore, Hong Kong, Saudi Arabia, Indonesia, Thailand and Malaysia to investigate the impact of building envelope on internal thermal performance and its influence on energy consumption. Though, research studies on residential building envelope design requirements to enhance the thermal performance of the high-rise residential building envelope in hot and humid climate are limited.

Lam (2000) conducted a study focused on the electricity consumption on the current design of high-rise residential buildings in Hong Kong. The paper predicted the energy saving by introducing 25 mm insulation and replacing all windows with tinted glass. It is reported that energy savings in the initial years are small, about 0.2% of the total electricity use in the residential sector in 1997. However, as older buildings are replaced by newer and better designs in subsequent years, this will have a bigger impact on the residential sector electricity consumption. Bojic et al. (2001) investigated the influence of wall insulation thickness and its position in the building envelope on peak cooling load and energy consumption. The study showed that cooling energy consumption could be reduced by approximately 7% by placing thermal insulation on the outside of the envelope walls.

An analysis of the building energy consumption in Hong Kong addresses peak cooling load and it can be seen that the building envelope design accounts for 36.7% of the peak cooling load, which is directly related to building design i.e. the responsibility of architects and engineers. The remaining percentage is related to building operation, which set on owners and operators responsibility (Lam & Li, 1999). Al-Mofeez (2007) has studied the possible energy saving from retrofitting a one-story house located in Dhahran, Saudi Arabia in a hot humid climate. The study shows that electrical consumption due to building envelope reduced by 40.3% on average and 34.3% in peak months. Yu et al. (2008) investigated the effects of building envelope components on cooling energy load in high-rise apartment in hot summer and cold winter zone of China. The study showed a saving of 8% on the annual electric consumption by replacing the 3mm normal clear glass of the Base Case windows with a double glazing with low-e, electro and reflective glass. Glazing characteristics have direct impact on the amount of heat gain/loss through the windows by either solar radiation or conduction heat transfer.

A study of Household Energy use by CETDEM (2006) – Center for Environment, Technology & Development, Malaysia found that, air conditioning takes up nearly 45% of the average household electricity consumption and air conditioning is the largest consumer of electricity in the home. In relation to energy efficiency and the use of sustainable energy in buildings, a few projects have been initiated to act as demonstration, educational and enhance public awareness programs in Malaysia. One of these projects is The LEO (Low Energy Office) Building in Putrajaya built as a demonstration project by the Ministry of Energy, Green Technology and Water, and was first occupied in 2004. Building energy management has been practiced since then and the building energy index was proposed at a maximum of 100 kWh/m^2/year. The building energy index in 2005 was 114 kWh/m^2/year but the index had decreased to 104 kWh/m^2/year in 2006 (Altamimi, 2011). Another example, The Energy Commission Malaysia designed to have an energy efficient building to house its headquarters. It was the third showcase energy efficient and sustainable building in Malaysia. The main objective of this Building is to achieve total energy savings by 65%, with an energy index of 85 kWh/m^2/year at 2,800 hours usage, as compared to a normal office building which has an energy index of 250 kWh/m^2/year (IEM, 2011).

The main objective of this paper is to investigate the energy performance of selected high-rise apartments in Kuala Lumpur. Possible energy savings due to passive envelope design measures integration are examined. This includes investigating the effect of thermal insulation and glazing type on potential energy savings.

2. Research Methodology

A theoretical modeling approach is used to achieve main objectives of this paper. Three recent high-rise apartment buildings were selected in Kuala Lumpur for this research. An energy simulation program is utilized for hourly model simulation under the selected weather conditions using a weather data of a typical metrological year (TMY). Selection of the suitable program depends on many factors related to program capabilities to simulate the problem at hand as well as other factors including program reliability, ease to use, etc. Several available simulation programs were reviewed and Energy Plus program was selected because of its reliability as it has been widely validated for accuracy and consistency. Energy Plus as a simulation program models heating, cooling, lighting, ventilating and other energy flows. It has many capabilities to simulate various time steps and plant integrated with heat balance-based zone simulation, thermal comfort and energy used and so on. It is a state-of-the-art software tool for checking building energy, carbon, lighting and thermal demands (Sabouri & Zain, 2011). After the three cases are modeled and energy simulation is performed, energy consumption and cooling load results are obtained and verified by comparing them with results of similar high-rise building apartment from previous research. The impact of various building envelope elements on building energy performance and expected energy savings are investigated including thermal insulation and glazing type.

3. Climatic Conditions of Kuala Lumpur

Kuala Lumpur is located at the latitude 3°7'N, and longitude 101°32'E, and the climate is classified tropical wet climate with no dry or cold season as it is constantly moist (year-round rainfall). The diurnal temperature range is of minimum 26–28°C and maximum 31– 33°C. The average difference is 6.7°C – 8.3°C with annual RH value ranges from 58 - 66% (Liggit & Milne, 2008).

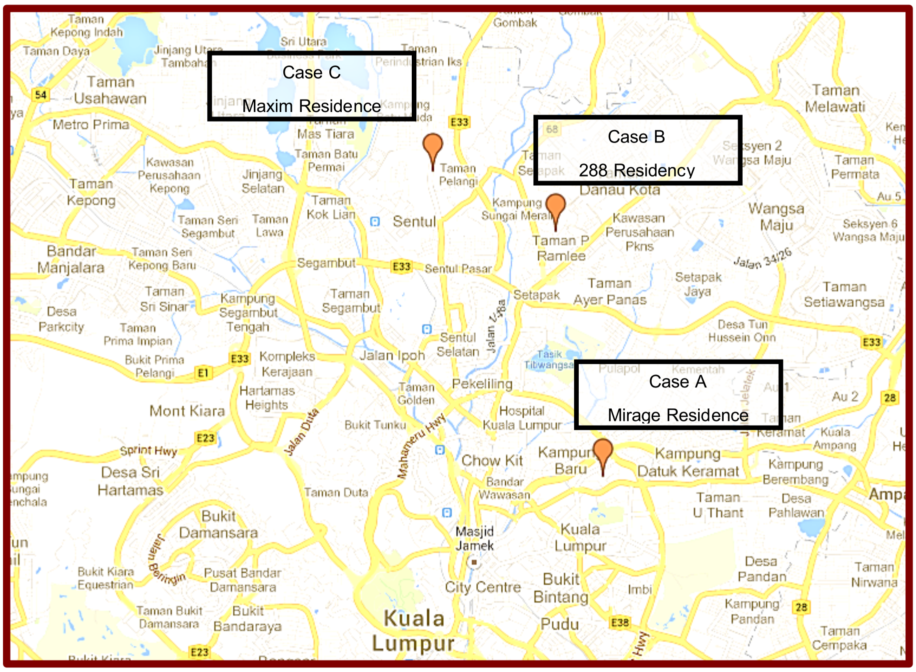

Figure 2: High-rise apartment building cases location

4. Modelling Cases Description and Characteristics

Three high-rise buildings apartments are selected for this study. These residential buildings are selected as they represent the trend of modern residential design which has mostly a glass façade that can be inconsistent to an energy-efficient building design in the tropics. They are located in Kula Lumpur, Malaysia. While the First case (Mirage Residence) is located at the Kula Lumpur city center, the other cases (288 Residency and Maxim Residence) are located at Sentul and Setapak respectively as shown in Figure 2.

The selected high-rise apartment buildings are consisted of different type of apartments based on number of bedrooms in each apartment. This paper will address only apartments with three bedrooms and each apartment has different floor area. While the apartment case (A) has gross area of 135 m^2, case (B) is 126 m^2 and case (C) is 86 m^2. Detailed floor plan for each apartment is shown in Figure 3. The main properties of each case are illustrated in Table 1. This includes walls and roof construction, window properties, HVAC system type and other building properties and information required for modeling and energy simulation.

The heating, ventilation and air-conditioning system is assumed to be split system unit direct expansion air-conditioner with a typical coefficient of performance (COP) of 2.7 (MS_1525, 2007). In addition, natural ventilation is applied by opening windows during unoccupied hours to reduce the thermal mass but windows are closed when the HVAC system is used. This ventilation algorithm is based on experimental study that a closed building in a hot climate of Malaysia would result in an overheated space during the early occupied hours of the evening (Al-Tamimi, 2011).

Case (A) Mirage Residence	Case (B) 228 Residency	Case (C) Maxim Residence

Figure 3: Apartment cases floor plan.

5. Results and Discussion

Following the formulation of cases and initial verification of input data, the case models are run through the Energy Plus program. Simulation results, including energy consumption, cooling energy, and peak cooling load, are analyzed for comparison with available data for similar buildings from the literature and illustrated in Figure 4. It is found that the total annual energy consumption for each model case varied from 5758 kWh for Case (A) with an average of 475

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kWh per month, 5387 kWh for Case (B) with an average of 435 kWh per month to 4732 kWh for Case (C) with an average of 392 kWh per month. This variation can be attributed to the difference in floor area and glazing area for each apartment which consequently has direct impact on heat gain or loss. These results are comparable to results obtained from previous studies conducted in Malaysia. A study to investigate the electricity profile for domestic and commercial sectors in Malaysia reported that the average electricity consumption for apartment with air-conditioner, water heater, and high capacity refrigerator is around 443.1 kWh per month (Ponniran et al., 2012). Another study on the cooling energy and passive energy savings strategies for Bungalow house in Malaysia stated that the average monthly energy consumption is about 640 kWh concerning that the total floor area for the case study is 243 m2 (Sabouri et al. 2011).

Table 1: Main properties of building cases.

	Case A	Case B	Case C
Location	Kuala Lumpur city center	Sentul, Kuala Lumpur	Setapak, Kuala Lumpur
Floor area	135 m^2	126 m^2	86 m^2
Construction:			
Walls	Masonry wall / concrete wall	Brick wall / RC wall	Clay brick / RC wall
roofs	RC flat roof	RC flat roof	RC flat roof
Windows	Aluminium frame glass window	Aluminium Framed Windows	Aluminium frame glass window
HVAC System	Residential Split unit system	ditto	ditto
Infiltration	0.5 ACH (Average building tightness)	ditto	ditto
Occupancy	4-5 people	ditto	ditto

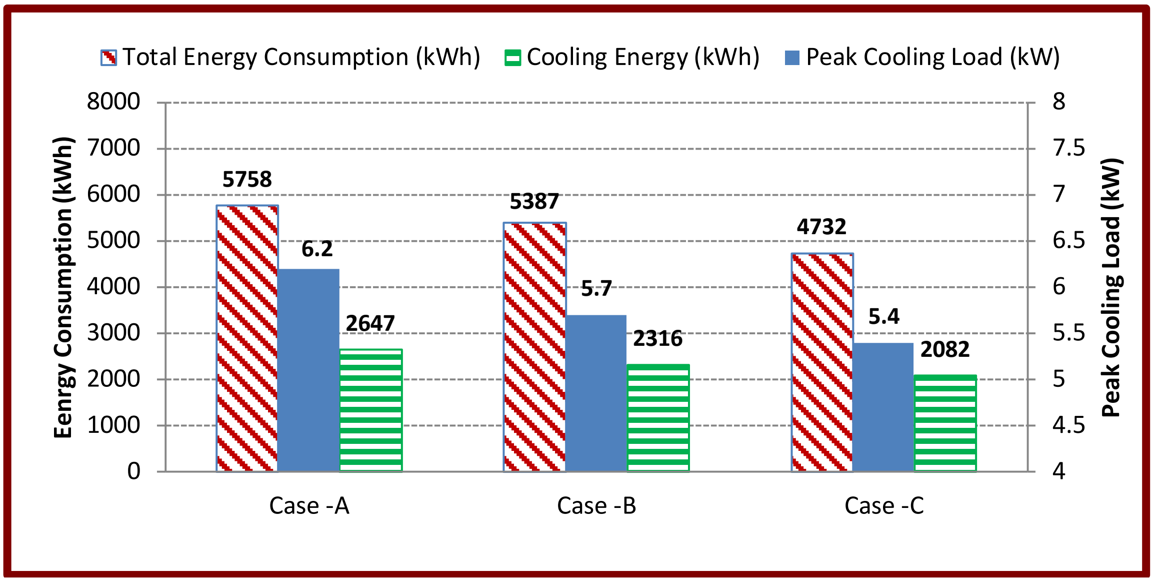


Figure 4: Annual energy performance results of the case studies.

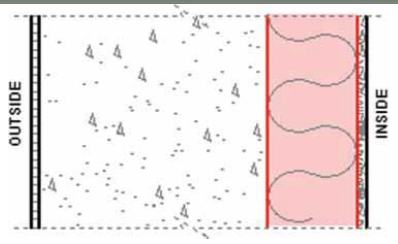
The simulation results showed that energy consumption for cooling accounts for about 40% to 42% of the total energy consumption which is in agreement with results from studies in similar climates and function (Cheung et al. 2005, Ponniera et al. 2012 and Sabouri et al. 2011).

The annual cooling energy for each case study varied from 2647 kWh for Case (A), 2316 kWh for Case (B) to 2082 kWh for Case (C). This difference in cooling energy is probably due to the variation in gross floor area and area of windows in the external walls for each apartment.

There are many energy conservation measures that can be applied to building envelope in order to minimize peak cooling load which has direct impact on cooling energy and ultimately lower energy consumption. Among of these measures is adding thermal insulation to the exterior walls with consideration to proper selection of thermal insulation properties and thickness. In addition, the appropriate selection of glazing type will affect the amount of heat loss or gain through windows and as result cooling energy requirements is reduced.

In this paper, the effects of mentioned above energy efficiency measures on the cooling load and cooling energy consumption are evaluated for each apartment. Two variables were selected for this evaluation, namely annual cooling energy and peak cooling load. Annual cooling energy is defined as total energy consumed by the cooling system to maintain the required thermal conditions of the space. Peak cooling load is defined as the maximum amount of heat that needs to be removed from the conditioned space in any single hour over the year in order to maintain the set point temperature. Lin & Ding (2006) conducted a research on the characteristics of bedroom cooling load in tropics and subtropics, using a building energy simulation program and found that peak cooling load usually happened during evening hours for most room orientations. Specifically, it is reported for west room at 17:00 to 19:00 and for south and north at 15:00 to 17:00. However, peak cooling load was found to be at 10:00 to 12:00 for east room. For each measure, the analysis indicates the change in both the cooling energy consumption and the peak cooling load of the modified envelope compared to basic apartment cases.

Table 2: External wall composition with thermal insulation

Layer description	Thickness (mm)	Thermal conductivity (W/mK)	Figure
Plaster	10	0.71	
Brick units / Concrete block units	200	1.3 /1.8	
ESP thermal insulation	25 – 100	0.03	
Gypsum Board	10	0.17	

5.1 Effect of Thermal Insulation

By adding thermal insulation to the external walls different levels of thermal resistance can be achieved building envelope. Extruded polystyrene (EPS) is one of the thermal insulation material that has been developed in recent years to be widely used in new buildings for energy-

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efficient building design requirements (Yu et al. 2008). The effect of adding thermal insulation on cooling load is evaluated by increasing the thickness of EPS in steps of 25mm to a maximum thickness of 100mm. the composition of the external wall is illustrated in Table 2.

The simulation results demonstrated that, for all apartment cases and thermal insulation thicknesses, cooling energy consumption and peak cooling load are significantly reduced when thermal insulation is added to the exterior walls. Figure 5 shows that cooling energy consumption is considerably minimized when 25 mm of (EPS) is applied on the inside surface of exterior wall by 14% to 14.5% for all cases.

Changing the thermal insulation of the external wall from 25 to 50mm resulted in a reduction of 17.5% to 18% in annual cooling energy consumption. It can be realized that, the higher the insulation thickness the greater the reduction in annual cooling energy consumption. However, the results showed that when thermal insulation thicker than 50mm is used slight reduction in cooling energy is achieved. Therefore it is not economical to use thermal insulation with a thickness greater than 50 mm as the effectiveness of the extra insulation is found to be stagnant.

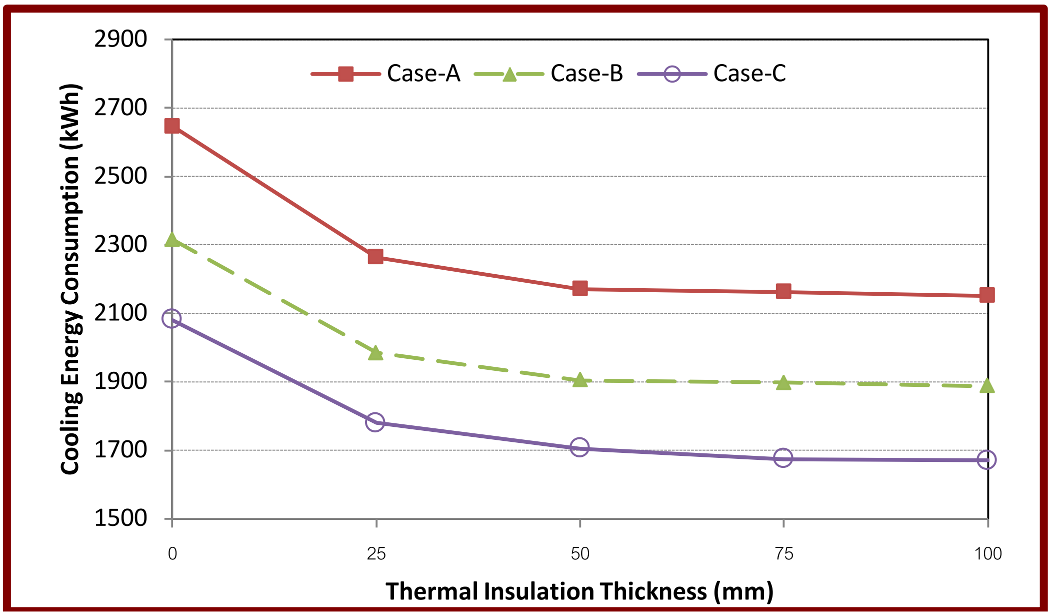

Figure 5: Effect of thermal insulation on annual cooling energy consumption

The introduction of thermal insulation to exterior walls significantly decreases the peak cooling load for all cases. The results, which are illustrated in Figure 6, show that a reduction of about 22% in peak cooling load is achieved when 25 mm of (EPS) is added to the exterior walls. A maximum reduction of about 29% in peak cooling load is obtained when 100 mm thermal insulation is placed on the inside surface of the external walls.

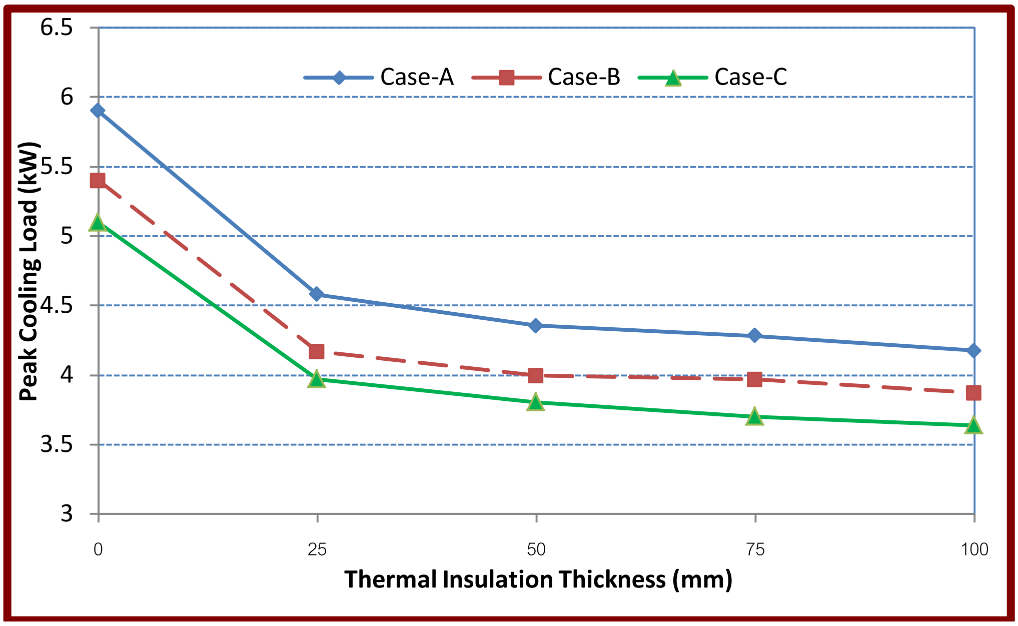

Figure 6: Effect of thermal insulation on peak cooling load.

5.2 Effect of glazing type

The glazing type and the number of glazing layers are among the critical parameters the designer must consider when designing windows. They can affect both the amount of light transmitted into the built space and the magnitude of solar heat gain, which in turn results in an increase in the cooling load. Many types of glazing with different thermal and physical characteristics are available for designers to choose from. Four different glazing types have been investigated in this study. Table 3 shows thermal and lighting characteristics of the four glazing types including the number of panes, the visible transmittance, and the shading coefficient (SC).

Table 3: Glazing types used

Glazing Type	No: of panes	Visible Transmittance	Shading Coefficient (SC)	Solar Heat Gain Coefficient (SHGC)	U-Value $W/m^2.K$
Single-Glazed Clear 6 mm	1	0.88	0.95	0.81	6.4
Single tinted 6 mm	1	0.65	0.73	0.62	6.0
Double-Glazed Clear 6/12/6 mm	2	0.78	0.81	0.70	2.74
Double-Glazed Clear Low-e 6/12/6 mm	2	0.74	0.65	0.56	1.78

The glazing type used in all apartment cases is single clear glass 6 mm with aluminum frame. This paper investigates the impact of using various glazing types on annual cooling energy consumption and peak cooling load. The simulation results, for all apartment cases, show that a considerable reduction in annual cooling energy consumption and peak cooling load would be achieved when glazing type is replaced.

Figure 7 shows that the replacement of single clear glass with single tinted glass reduce the annual cooling energy by 7% to 9.5%. In addition, using double glass clear would result in

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reduction of about 10% to 13.5% in energy consumed be cooling systems. The maximum savings in cooling energy would be up to 19% by the replacement of single clear glass with double clear glass low-e. It is found that the shading coefficient value for a specific glazing type is the main factor that determines the energy performance of a particular window. The results prove that the lower the shading coefficient value, the lower the cooling energy consumption.

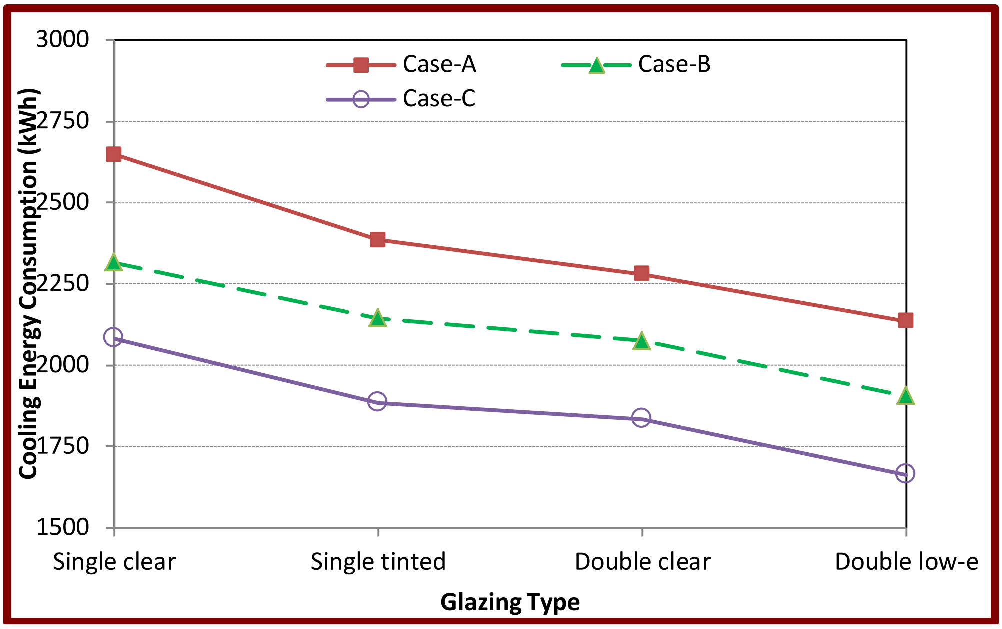

Figure 7: Effect of various glazing types on annual cooling energy consumption

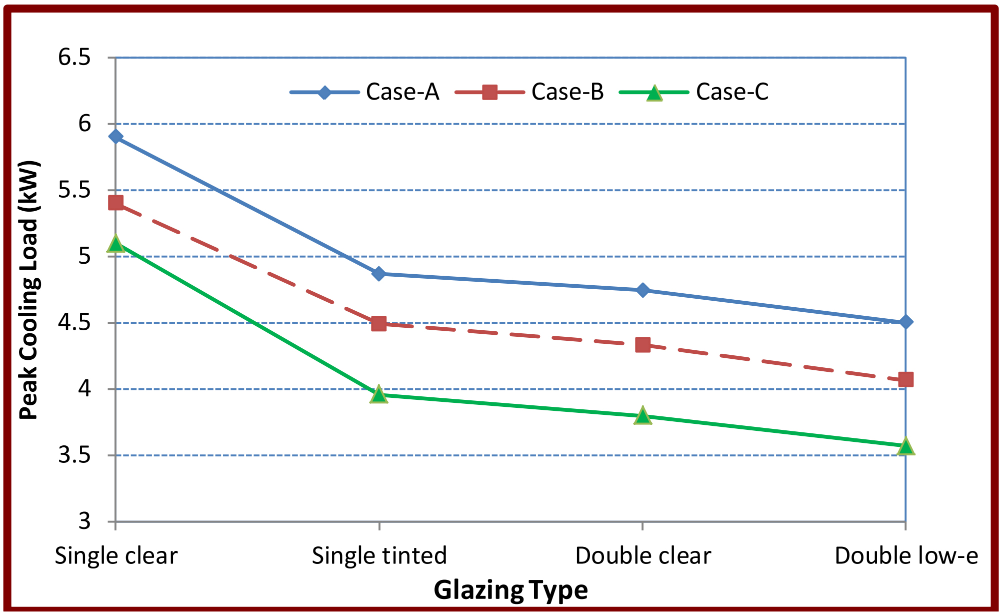

Figure 8: Effect of various glazing types on peak cooling load.

The impact of the replacement of glazing type on peak cooling load is illustrated in Figure 8. The results show that window glazing system has significant effect on peak cooling load. The use of double clear glazed windows can reduce heat conduction coefficient and peak cooling load more than single clear glazing by up to 23%. However, the use of double glass clear low-e would result in a considerable reduction in peak cooling load. This reduction can reach up to 30% and this can be attributed to the thermal properties of this glazing type which prevent most of the direct heat gain.

6. Conclusions

Residential buildings, particularly in hot climates, are a major consumer of electric energy with air-conditioning systems accounting for a large proportion of total energy consumption. There has been a rising awareness of energy efficient design and green buildings all around the world and in particular in Malaysia. This is proved by the recent development of Malaysian Green Building Index. There are many energy conservation measures that can be applied to building envelope to reduce electric energy consumption. This includes the proper use of thermal insulation in roof and exterior walls and also the selection of glazing type installed in windows.

Therefore, this paper investigates the energy performance of three samples of apartments in different high-rise residential buildings in different locations in Kula Lumpur, Malaysia. This is done using Energy Plus software under the tropical climate of Malaysia. This study intent was to highlight on the expected reduction in annual electrical energy consumed by cooling systems and peak cooling load when some passive envelope measures are applied, namely the addition of thermal insulation to the exterior walls and the replacement of glazing type.

It is found that exterior wall thermal insulation provide a significant reduction in both annual cooling energy and peak cooling load up to 20% and 29%, respectively. This reduction depends mainly on thermal insulation thickness. The replacement of single glass clear with double low-e glass would result in a maximum energy savings in annual cooling energy up to 19% and decrease in peak cooling load up to 30% comparing with other glazing types.

The simulation results provide an indication that there is high potential of energy savings in electric energy consumed be air-conditioning systems in high-rise apartment buildings in Malaysia when energy conservation measures are properly applied to building envelope. This study recommends the utilization of thermal modeling in building design which can provide helpful assistance to architects and building designers to evaluate the effectiveness various design alternatives for energy efficiency at the early stage of building design.

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