# Enhancing energy efficiency of office buildings in a tropical climate, Malaysia

S.Sadrzadehrafiei, K.Sopian, S.Mat, C.Lim, H.S.Hashim, A. Zaharim

***Abstract*—** - This study investigates the enhancement of office building energy efficiency, based on the effects of passive solar design techniques. Energy efficiency is potentially achieved by installing insulation materials in the external walls and roofs of buildings, and applying advanced glazing. The Chancellery office building of University Kebangsaan Malaysia was chosen as the test bed for simulation studies. Integrated Environmental Solutions (IES) software was used to model the office building, as well as analyze thermal performance and cost benefits. This study found that by applying advanced glazing and insulation to the external walls and roofs of a building, annual energy consumption can be reduced by 215790 (KWh), in comparison to a building without insulation and advanced glazing.

***Keywords*—**Building simulation, Energy consumption, Energy saving, Low-e glazing, Office building, Thermal insulation

## I. Introduction

ENERGY is increasingly costly and the condition is worsened by global warming due to green house gas emissions[1]. Enhancing energy efficiency in buildings is one of the most cost-effective measures in minimizing carbon dioxide emission(Lombard et al., 2008; Chow, 2001; Uchiyama, 2002) [2].Office development is one of the fastest growing sectors in the construction industry, with office buildings consuming about 70-300 kW h/m$^2$ of energy, which is 10-20 times higher than in residential sectors [3]. Sadrzadehrafiei et al. [4] conveyed that in a typical mid-rise office building in Malaysia, air conditioners utilized the most energy at 58%, followed by lighting (20%), office equipment (19%), and other (3%).

The purpose of this study is to reduce energy demand by applying advanced glazing and insulation material in the external walls and roofs of buildings.

Glazing systems usually have a significant effect on whole building energy utilization [5]. According to Atikol et al. [6], heat loss through building walls and windows is about 45%, therefore it is possible to save energy through enhancing window performance from a heat loss perspective. In a research paper, Milorad Boji [7] estimated that energy can be saved by applying advanced glazing to a representative high-rise residential building in Hong Kong, utilizing the simulation software Energy Plus. It was established that implementing low-e glazing would initiate a decrease in cooling electricity usage by up to 4.2%. Savings achieved by implementing low-e double glazing would be up to 1.9%, double clear glazing up to 3.7%, and clear plus low-e glazing up to 6.6%. Francis Yik [8] appraised the effect of utilizing switchable glazing on energy use for space cooling. Using software, EnergyPlus, is found that implementation of switchable glazing would guide to a decrease in yearly cooling electricity consumption by up to 6.6% where the substantial amount depends upon the existence of overhangs, orientation of building wings, sorts and locations of rooms.

Several studies have been done on energy and comfort efficiency of innovative glazing materials, whereas relatively little interest has been devoted to reversible windows [9]. Gugliermetti [9] examined potential energy savings from using fully reversible windows in residential buildings of several Italian locations. In another study by Feuermann et al. [10] winter energy savings were evaluated for reversible windows used in different locations, without taking into account indoor thermal environment or summer energy consumption.

The application of insulation material as a building component can influence its performance regarding transient heat flow [11]. Meanwhile, energy consumed by air conditioning systems can be minimized with insulation. Thermal insulation is therefore the alternative choice, for it is cost effective due to energy reduction. However, insulation cost is directly proportional to insulation thickness.

Bolatturk [12] explored several analyses on the use of insulation in external building walls. The results illustrate that maximum insulation thickness ranges from 2-17cm, payback duration is 1.3-4.5 and energy savings are 22-79%. Comaklı and Yuksel [13] examined ideal insulation thickness in the three coldest Turkish cities using day temperatures, and centered their research on analyzing life cycle cost. According to the findings, the saving in cold cities may be up to 12.14$/m$^2$ of wall area over a 10-year duration.In Denizli, Turkey, Dombayci [14] discovered that by using expanded polystyrene as insulation material in the external walls of buildings, energy consumption decreased by 40.6% while $CO_2$ and $SO_2$ emissions were reduced by 41.53%, with coal as the energy source. Al-Sanea [15] compared the thermal performance of different roofs and showed that a slightly

Manuscript received November 29, 2011. Manuscript received April 6, 2011.This research is funded by the Transition towards a Sustainable Campus under the reference number K014825, UKM-AP-PLW-04-2009/1.

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better thermal performance was achieved by placing the insulation closer to the inside surface of the roof; however, this exposed the water proofing membrane to larger temperature fluctuations. Sodha et al. [16] examined optimum insulation thickness inside and outside the roof in order to achieve maximum heat flux levels entering via the roof. It was discovered that when the inside and outside insulation thicknesses were equal, maximum load level occurred. In another study by Ozel [17], the most suitable location of roof insulation was investigated from the point view of maximum load leveling. It was concluded that the best load leveling was obtained when insulation layers of the same thickness were placed, first outdoors, second in the middle and the third layer at the indoor roof surface.

This present study was undertaken to evaluate energy saving and consumption when applying advanced glazing and insulation material to external walls and roofs of office buildings in Malaysia.

*A. Overview of the electricity consumption and $CO_2$ emission in Malaysia*

A high economic growth in Malaysia over the past three decades has seen a dramatic increase in energy consumption. From 1980 to 2009, total electricity consumed and gross domestic product (GDP) increased by 9.2% and 6.2%, respectively [18]. Figure 1 shows that Malaysia has the highest electricity consumption among all ASEAN countries. Figure 2 shows the distribution of total energy consumption in Malaysian sectors. It turns out that the commercial sector is the second-largest user, accounting for about 32% of total energy consumed in Malaysia [19].

With increasing energy consumption in sustaining the country's growth over the years, $CO_2$ emission will have an upward trend as long as fossil fuel use as the critical part in energy mix. As illustrated in Figure 3, the total CO2 emission in Malaysia has increased towards the end of 1990s and reached more than 160 million metric tonnes (MMt) by 2003[20].

## II. Methodology

IES <VE-Pro> (Integrated Environmental Solution) was used to model the chosen office building located in Bangi, Malaysia. The geographic coordinates of Malaysia are latitude 3.12$^o$N, longitude 101.55$^o$E, while temperatures are variable and there is high humidity. Malaysia's hottest time is around March, at 27.8$^o$C [21]. As shown in figure 4 with the annual weather data, maximum dry-wet bulbs are 34.90$^o$C and 26.50$^o$C, respectively.

*A. An Overview of the Case Study Building*

The proposed, chosen building is the Chancellery office building, an iconic landmark at UKM (University Kebangsaan Malaysia), located in Bangi, Malaysia. The selected building is a typical, six-story office building which contains 14848m$^2$ of assignable, instructional space including office spaces,

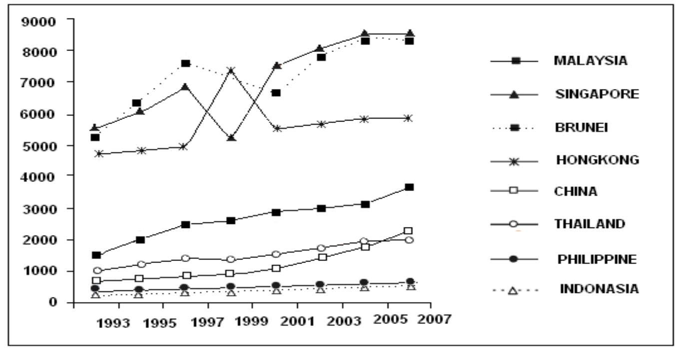


Fig.1.Electricity consumption in kilowatt hour per capita in ASEAN countries [17]

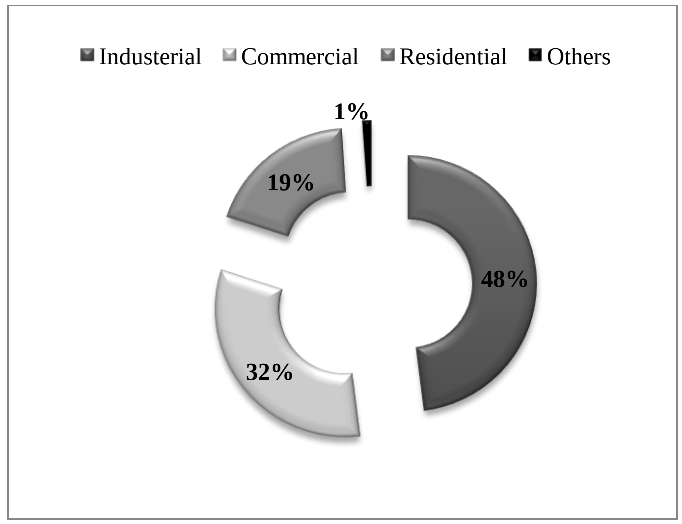


Fig.2. Statistics of energy uses in Malaysia (EC, 2007)

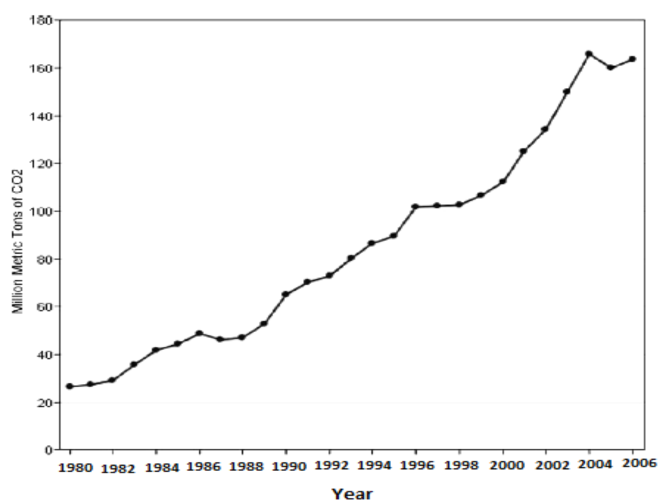


Fig.3.Total $CO_2$ emission in Malaysia [20]

lobby, meeting rooms and restaurants. The material composition of the walls, windows, and other elements of the building fabric are described in Tables I and II. As for glazing constructions, layer properties include solar transmittance, absorbance and reflection characteristics.

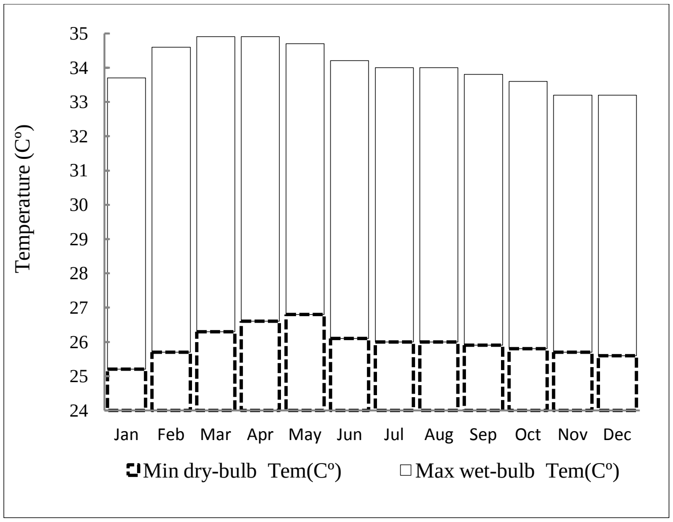


Fig.4. Annual dry-wet bulb temperature, Kuala - Lumpur, Malaysia

Table I. Material properties of glazing

| Description | Thickness m | Conductivity W/(m·K) | Solar transmittance | Outside reflectance | Inside reflectance |
|---|---|---|---|---|---|
| External Window | 0.006 | 1.06 | 0.78 | 0.07 | 0.07 |
| Internal Window | 0.004 | 1.06 | 0.82 | 0.07 | 0.07 |

Table II. Material properties of building

| Description | Material | Thickness m | Conductivity W/(m·K) | Density kg/m³ | Specific heat capacity J/(kg·K) |
|---|---|---|---|---|---|
| External wall | Brickwork<br>Plaster | 0.117<br>0.02 | 0.84<br>0.5 | 1700<br>1300 | 800<br>1000 |
| Internal Ceiling/floors | Cast Concrete<br>Cavity<br>Plaster | 0.1<br>0.012<br>0.01 | 1.4<br><br>0.5 | 2100<br><br>1300 | 840<br><br>1000 |
| Metal Roof | Steel<br>Bitumen layer<br>Glass wool | 0.01<br>0.005<br>0.03 | 50<br>0.5<br>0.04 | 7800<br>1700<br>200 | 480<br>1000<br>670 |
| Flat Roof | Stone<br>Bitumen layer<br>Cast Concrete | 0.01<br>0.005<br>0.15 | 0.96<br>0.5<br>1.13 | 1800<br>1700<br>2000 | 1000<br>1000<br>1000 |

*B. IES<VE-Pro> simulation software*

The building energy simulation program IES <VE-Pro> (Integrated Environment Solution) was used for the present study to predict annual energy used by the Chancellery office building (Fig.5). This software is a flexible, integrated assessment system that results in productivity and excellence in every aspect of sustainable building design, and is employed by leading sustainable design professionals worldwide. Weather data in these formats is available for a large number of sites worldwide [22]. In this study, climate data for Malaysia and weather data for Kuala Lumpur were adopted for analysis. The summary on data input for energy audit is as follows: data weather and site locations, building

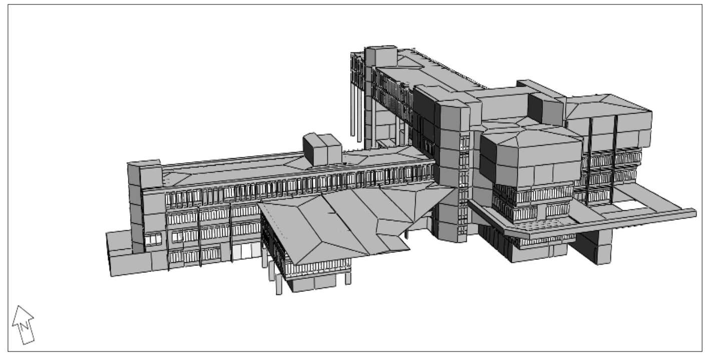

Fig.5. 3D view of the Chancellery office building model developed in IES< VE-PRO> 6.2.0.1

Table III: Building internal gain

| Description | Value | Units |
|---|---|---|
| Occupants | 9 | Person/m$^2$ |
| Lightings | 18 | W/m$^2$ |
| Office equipment | | |
| Computers | 5 | W/m$^2$ |
| Printers | 20 | W/m$^2$ |
| Copy machines | 9 | W/m$^2$ |

construction, specific variation profiles of casual gain, ventilation and set points, light and office equipment internal gain from occupants, and cooling system setting(Table III).
The simulation results of IES have been validated through comparison between field study energy consumption measurement by using power logger and IES simulation results. IES calculates conduction, convective and radiant heat transfer effects using hourly weather data.

## III. Energy Analysis

Based on the building characteristics described above, annual electricity consumption of the selected building was calculated by using electricity per hour at the IES. The simulation runs from 1 January to 31 December.

### *A. Five cases evaluating energy consumption*

Using the same building footprint and structure, four cases were created for comparison.

First case: Original, representing typical Malaysian office buildings

a) Single glass
b) Non-insulated roofs and walls.

Second case: Improved glazing construction

a) Applying double low-e glazing
b) Applying double low-e reverse glazing

Table IV shows the optical properties of glass obtained from the glass window library. All windows changed to double low-e and low-e reverse glazing for energy efficiency since using advanced glazed windows in exposed areas can reduce heat loss compared to single-glazed windows. The most suitable type of window was chosen according to lower energy consumption.

Third case: Improved exterior wall insulation

a) Adding 4cm extrude-polystyrene thermal insulation.
b) Adding 4cm polyurethane thermal insulation.

Table IV shows the selected external wall insulation material properties.

Fourth case: Improved roof insulation

a) Adding 4cm glass fiber quilt thermal insulation
b) Adding 4cm extrude-polystyrene thermal insulation

Table V shows the selected roof insulation material properties.

Fifth case (proposed):

a) Improved glazing construction and exterior wall and roof insulation

| Description | Material | Thickness (mm) | Solar reflectance | | Solar transmittance | IR hemispherical emissivity | |
|---|---|---|---|---|---|---|---|
| | | | front | back | | front | back |
| Double Low-e glazing | Low-e pane | 32 | 0.331 | 0.39 | 0.496 | 0.84 | 0.033 |
| | cavity | 12 | | | | | |
| | Low-e pane | 57 | 0.173 | 0.25 | 0.582 | 0.84 | 0.083 |
| Low-e reverse | Low-e pane | 60 | 0.22 | 0.19 | 0.63 | 0.1 | 0.84 |

Table.III: Optical properties of advanced glazing

Table IV. Data of Externall Wall Insulation Materials

| Type of insulation | Thickness (m) | Thermal conductivity W/(m-K) | Density kg/m$^3$ | pecific heat capacity J/(kg-K) |
|---|---|---|---|---|
| Polyurethane | 0.04 | 0.025 | 30 | 1400 |
| Extrude polystyrene | 0.04 | 0.029 | 35 | 1380 |

Table V. Data of Roof Insulation Materials

| Type of insulation | Thickness (m) | Thermal conductivity W/(m-K) | Density kg/m$^3$ | Specific heat capacity J/(kg-K) |
|---|---|---|---|---|
| Glass fiber Quilt | 0.04 | 0.04 | 12 | 840 |
| Extrude polystyrene | 0.04 | 0.029 | 35 | 1380 |

## IV. IES RESULTS

### A. *First Case (Original)*

First case represents typical Malaysian office buildings. Exterior walls and roofs have no insulation and windows have single clear glass. The annual electricity consumption for building the underlying cause is selected in Fig.5. The annual consumption of electricity energy consumption for this project was 2265.4 (MWh). Of the total building electricity consumption, 58% is from space air conditioning like cooling and ventilation, followed by lighting (20%), office equipment and other (19%) and (3%). These findings are in agreement with previous results by Saidur[18] which indicated that office building air conditioners consumed most energy (57%) followed by lighting (19%), lifts and pumps (18%) and other equipment (6%).Results of the IES run on building energy performance for first case is shown on figures 6 and 7.

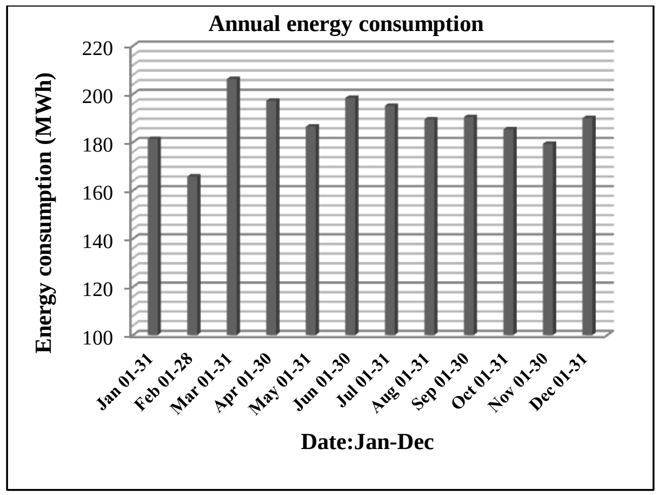


Fig.6. Results of the IES run on Chancellery building energy performance for the base case

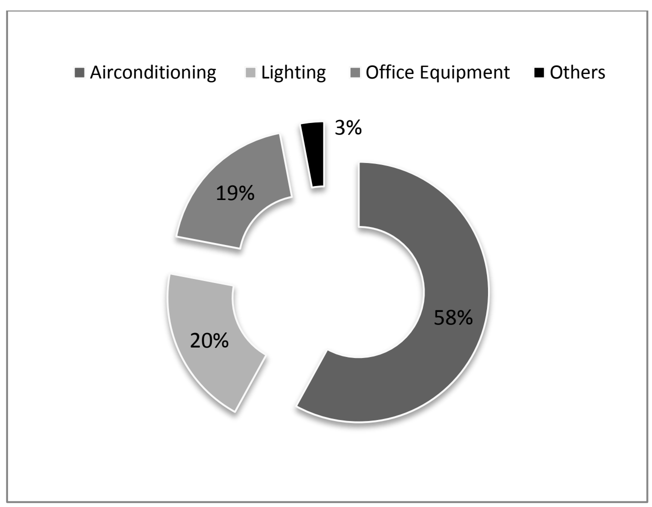


Fig.7. Total energy consumption by all equipments and their breakdown

### *B. Second Case*

The reduction in annual cooling energy used in selected jobs due to changes in the standard glass (clear single) to the double low-e and low-e reverse glazing studied, reduces the percentage of annual cooling energy consumption in reference to the annual energy consumed by cooling available when the building uses standard glass. Reductions in annual cooling energy for different windows are shown in figures 8 and 9.

Results illustrate that application of double low-e glazing provide the higher energy saving compare to low-e reverse glazing. It shows that application of double glazing with low-e pane would yield a saving in annual electricity consumption of 105687 KWh compare to energy consumption when single clear glazing is used.

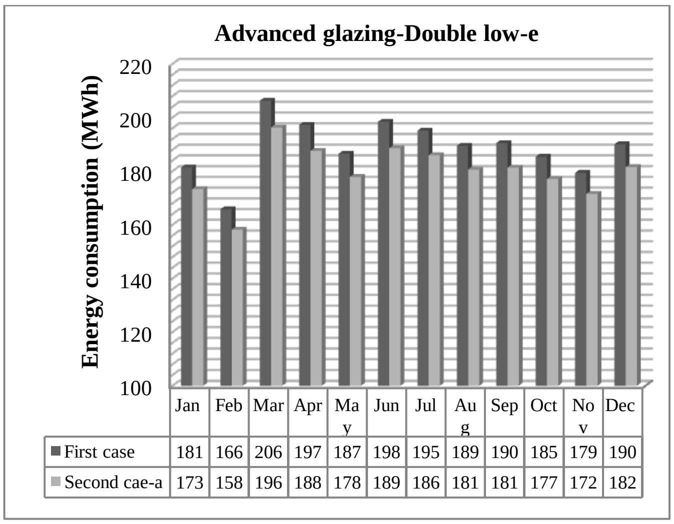


Fig.8. Annual energy consumption, using double low-e glazing

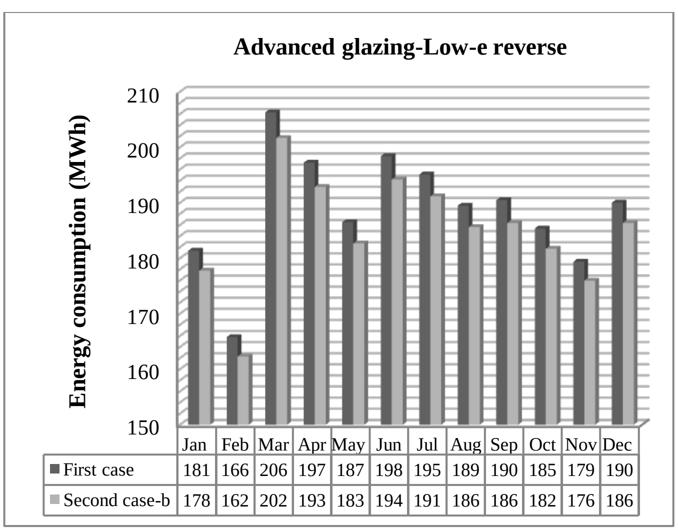


Fig.9. Annual energy consumption, using low-e reverse glazing

### *C. Third case*

Simulation results indicate that in buildings with external wall thermal insulation, cooling load and energy consumption decrease. Figures 10 and 11 illustrates extrude-polystyrene and polyurethane insulation thickness of 4cm and how they generally decreases annual energy consumption. Compare to extrude-polystyrene, the application of polyurethane as insulation material would lead to lower energy consumption and annual energy saving of 59995.6 kWh.

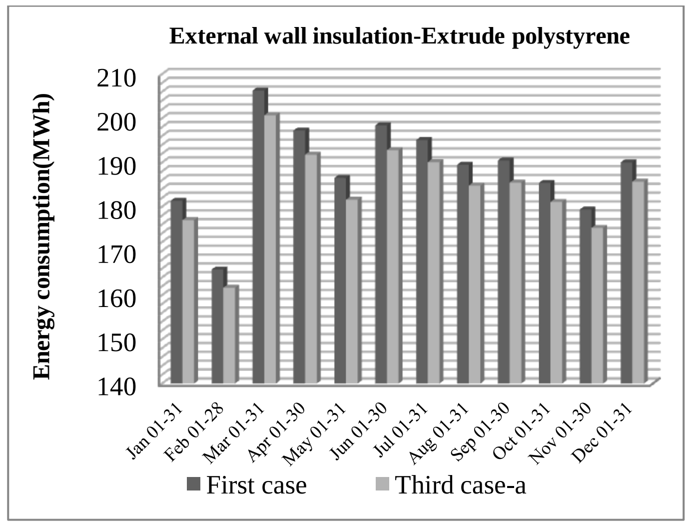


Fig.10. Annual energy consumption, using extrude polystyrene as wall insulation

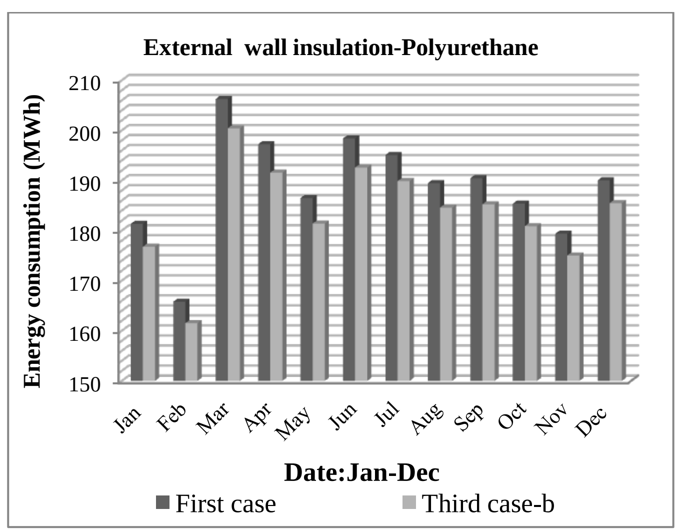


Fig.11. Annual energy consumption, using polyurethane as wall insulation

*D. Forth case*

The reduction in the yearly electricity energy consumption due to application of glass fiber quilt and extrude polystyrene as roof insulation was observed. The application of extrude polystyrene insulation thickness of 4 cm demonstrate annual energy saving of 33227.3 KWh, while using glass fiber quilt would reduce the yearly cooling electricity consumption of 30896 KWh.

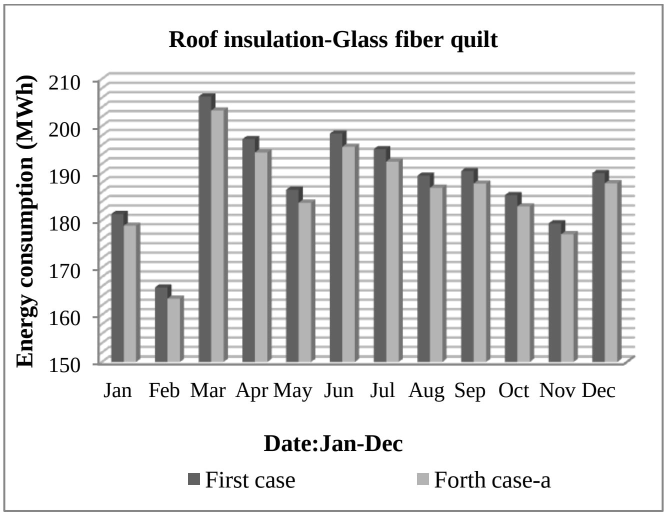


Fig.12. Annual energy consumption, using glass fiber quilt as roof insulation

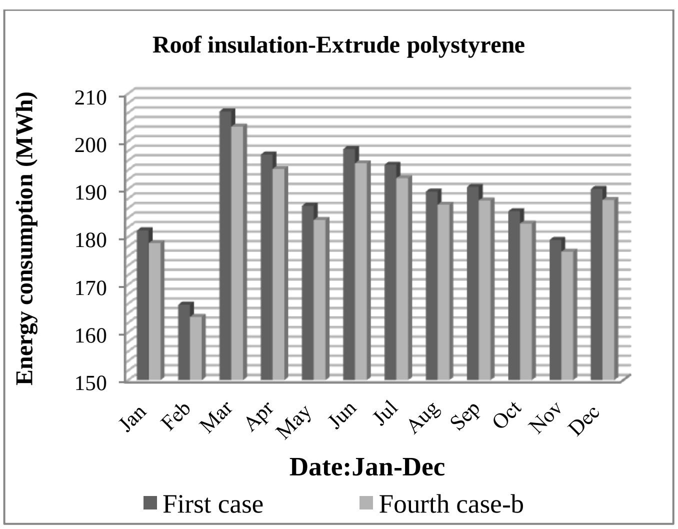


Fig.13. Annual energy consumption, using extrude polystyrene as roof insulation

*Fifth case, (proposed)*

Results illustrate that double low-e glazing, polyurethane as external wall insulation and extrude-polystyrene as roof insulation, provide higher energy saving. Figure 14 shows the data regarding extrude polystyrene as insulating material in roof, polyurethane as wall insulation material and double low-e glazing as energy conservation opportunities. It illustrates that a 215709.8 KWh reduction in total energy consumption was achieved. The estimated energy saved is through the application of double low-e glazing and walls and roof insulation. Compared to the first case, the application of advanced glazing and insulation would lead to considerable reduction in the yearly electricity consumption (Fig.15).

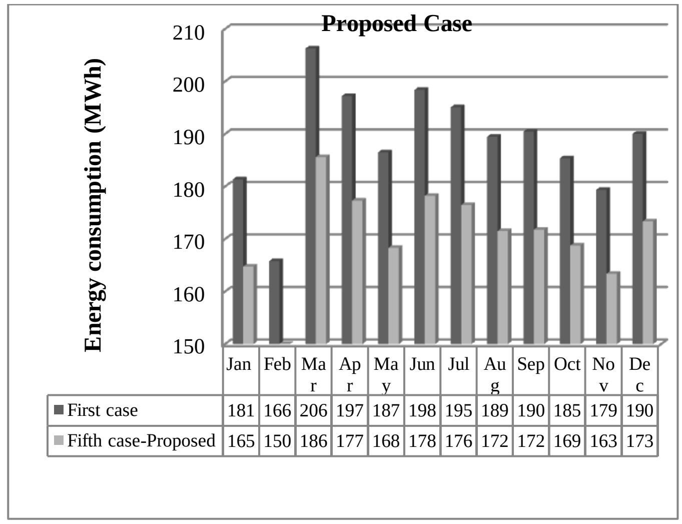


Fig.14. Annual energy consumption, using extrude polystyrene as roof insulation

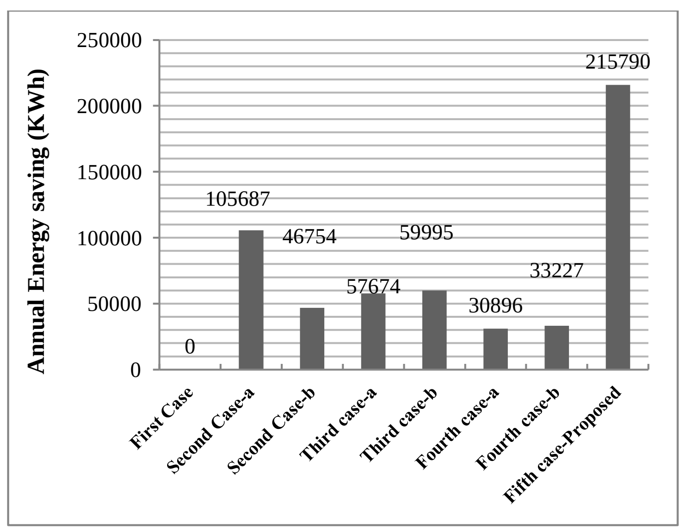


Fig.15. Annual energy saving, using extrude polystyrene as roof insulation

Results indicate that application of double low-e glazing demonstrate the highest energy saving, whereas adding 4cm glass fiber quilt roof thermal insulation demonstrate the lowest annual energy saving of 30896 KWh.

From the simulation results, it is obvious that with wall and roof insulation and advanced glazing, both fuel consumed and consequently, emissions, decrease. As it can be seen in figures 16 and 17, proposed case demonstrated the highest annual emission reduction followed by double low-e glazing. Double low-e glazing shows the lowest electricity consumption (2218715 KWh/year) and emissions of 1116608 (kg CO2). Results show that application of extrude polystyrene and polyurethane to the external wall of building demonstrate annual emission reduction of 29818 and 31018 kg $CO_2$ respectively. Glass fiber quilt and extrude-polystyrene as roof insulation materials with 4 cm thickness was found to have the lowest emission reduction of 15937 and 17178 kg$CO_2$ respectively.

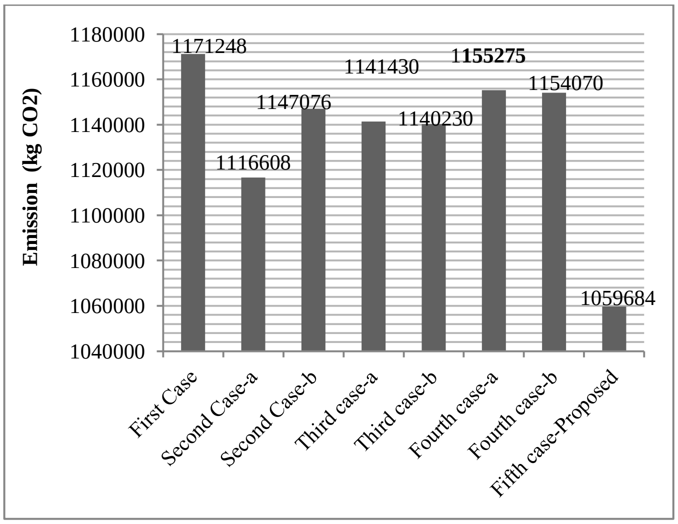


Fig 16: Annual $CO_2$ emission

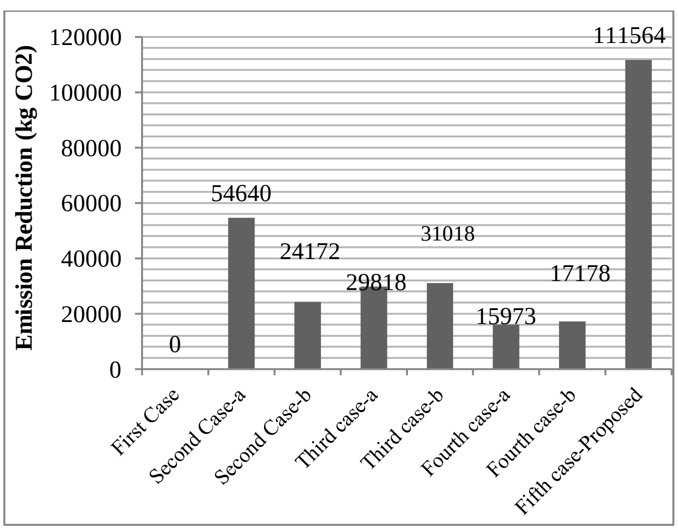


Fig.17. Annual emission reduction

## V. Conclusion

This paper examined energy consumed and saved after installing advanced glazing and insulation material into air-conditioned building walls and roofs in Malaysia. The decrease in electricity consumption was investigated with IES simulation software. The yearly savings in energy consumption by applying advanced glazing and insulation to the external walls and roofs of a building were found to be:

Double low-e glazing-up to 105687.5 KWh

- Low-e reverse glazing- up to 46754.9 KWh
- Extrude-polystyrene (external wall insulation) - 57674.5 KWh
- Polyurethane- (external wall insulation) -up to 59995.6 KWh
- Glass fibers quilt (roof insulation) - up to 30896 KWh
- Extrude polystyrene (roof insulation) - up to 33227.3 KWh

The results demonstrate that by applying double low-e glazing, polyurethane wall insulation material and extrude-polystyrene as roof insulation material, energy consumption is lowered to a minimum and can reach 2049 MWh.

## References

[1] L.P. Lombard, O. Jose, P. Christine, "A review on buildings energy consumption information," *Energy and Building*, 40 (3), 2008, pp.394–398.

[2] H. Abdul-Rahman, C. Wang, M. Y. Kho, **"**Potentials for sustainable improvement in building energy efficiency: Case studies in tropical zone," *International Journal of the Physical Sciences* Vol. 6(2), 2011, pp. 325-339.

[3] L.Yang, J. C. Lam, C.L. Tsang, 2008. "Energy performance of building envelopes in different climate zones in China," *Applied Energy*, 85, 2008, pp. 800–817.

[4] S.Sadrzadehrafiei, K.Sopian S.Mat, C.Lim, "Energy consumption and energy saving in Malaysian office buildings," Models and Methods in Applied Sciences, ISBN: 978-1-61804-044-2.

[5] H. Shen, A. Tzempelikos, "Daylighting performance of offices with controlled shades," Recent Researches in Geography, Geology, Energy, Environment and Biomedicine, ISBN: 978-1-61804-022-0

[6] U. Atikol, H. Asssefi, M. R. Azzian, M. Gharebaghi, 2008,Effect of demand-side management on the feasibility of high performance windows, 3rd IASME/WSEAS Int. Conf. on Energy & Environment, University of Cambridge, UK, February 23-25.

[7] M. Bojic, F.Yikb, "Application of advanced glazing to high-rise residential buildings in Hong Kong," *Building and Environment*, 42, 2007, pp. 820–828.

[8] Y.Francis, B. Milorad.2006, "Application of switchable glazing to high-rise residential buildings in Hong Kong," *Energy Build*, 38, 2006, pp.463–467.

[9] F. Gugliermetti, F. Bisegna, "Saving energy in residential buildings: The use of fully reversible windows," *Energy* ,32 ,2007,pp. 1235–1247

[10] J.Schultz, S.Svendsen, "Winsim: a simple simulation program for evaluating the influence of windows on heating demand and risk of overheating," *Solar Energy*, Volume 63, 4., October 1998, pp. 251-258

[11] M.GR. Vrachopoulos, M.K. Koukou, G. Kotsivelos, E. Kravvaritis, P. Ioannidou, **"**Experimental evaluation of the performance of reflective insulation for improvement of indoor thermal environmental conditions," Proceedings of the 2006 IASME/WSEAS International Conference on Energy & Environmental Systems, Chalkida, Greece, May 8-10, 2006 ,pp38-42.

[12] A. Bolatturk, "Optimum insulation thickness for building walls with respect to cooling and heating degree-hours in the warmest zone of Turkey." *Building and Environment* , 43(6), 2008,pp.1055-1064

[13] K. Comakli, B. Yuksel, "Optimum insulation thickness of external walls for energy saving," *Applied Thermal Engineering*, 23, 2003, pp. 473–479.

[14] OA. Dombyci, "The environmental impact of optimum insulation thickness for external walls of buildings," *Building and Environment*; 42(11), 2007, 3855-3859.

[15] S.A. Al-Sanea, "Thermal performance of building roof elements," *Building and Environment*, 37, 2002, pp.665–675.

[16] M.S Sodha, S.C. Kaushik, GN Tiwari, I.C. Goyal, M. Malik, A.K. Khatry, "Optimum distiribution of insulation inside and outside the roof," *Building and Environment* ,14,1997,pp.47–52.

[17] M. Ozel_, K. Pihtili, "Investigation of the most suitable location of insulation appling on building roof from maximum load levelling point of view," *Building and Environment* ,42 ,2007,pp. 2360–2368.

[18] H. A. Bekhet, N. S. bt Othman, "Causality analysis among electricity consumption, consumer expenditure, gross domestic product (GDP) and foreign direct investment (FDI): Case study of Malaysia," *Journal of Economics and International Finance* Vol. 3(4),2011, pp. 228-235.

[19] R. Saidur, "Energy consumption, energy savings, and emission analysis in Malaysian office buildings," *Energy Policy*,37,2009,pp.4104-4013.

[20] T. H. Oh, S. C. Chua, "Energy efficiency and carbon trading potential in Malaysia," *Renewable and Sustainable Energy Reviews* ,14 ,2010, pp. 2095–2103

[21] Malaysian Meteorological Service, Annual Summary of Meteorological Observation, Malaysian Meteorological Service, Kuala Lumpur, Malaysia, 2002

[22] http://www.iesve.com