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## Assessment of the variation impacts of window on energy consumption and carbon footprint

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### Abstract

Energy efficiency has become increasingly important to the community, regulatory bodies and industry in recent years. Dominant per capita energy consumption is associated with home used energy resources which also contribute to greenhouse gases. The main objective of this work is to evaluate the direct impacts of variations of multi-glazed windows on the sustainability through BIM software and determining the rate of energy consumption and carbon foot print in accordance with the implemented changes in a building. The altered parameters in this study are number of glazed layers, filled gases, sizes and orientations of the windows. The case study is a 56.25 m<sup>2</sup> hut which is built in one level and located in Kuala Lumpur. The simulation is carried out by using ArchiCad 14 software which is one of the pioneers in BIM and its new sustainability plug-in integrated into this software known as Grafosoft EcoDesigner. It is concluded that the type of gas used in double and triple glazed windows and increasing the size of windows to 41% of an area of the window to floor surface ratio do not differ significantly from 34% of area of window to floor surface ratio with regard to the energy consumption and carbon footprint in tropical areas.

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*Keywords:* window; glazing systems; energy consumption; carbon footprint; sustainability.

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### 1. Introduction

The term sustainable has recently gained popularity in Malaysian construction industry Master Plan (2005 –2015) as a crucial priority for the Malaysian construction industry [1]. The Malaysian Green

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Building Index (GBI) has been developed currently by Association of Consulting Engineers Malaysia (ACEM) and Pertubuhan Arkitek Malaysia (PAM) in order for enhancing sustainability in the built environment. Despite widespread calls for reducing in energy usage and natural resources exploitation Sustainability and environmental issues are still among those cases that have received little consideration. When sustainability issues are considered, it is usually with respect to energy consumption or the choice of materials [2]. Energy consumption is the main responsible for emissions of greenhouse worldwide. It is estimated that the construction sector accounts for about 35% of greenhouse gas emissions [3]. The International Energy Agency predicts that the global energy demand will increase by more than 50% by 2030 if policies remain unchanged and more than 60% of this increase respects to developing countries. This will lead to a 52% increase in emissions of carbon dioxide (CO<sub>2</sub>), the main greenhouse gas [4].

Windows actively contribute to heat transmittance between building and the environment [5]. In USA almost 3% of overall energy, is wasted through windows, while in Sweden this amount reaches to 7%. Solar heat gain has a substantial function in the thermal performance determination of a building. For designers increasing or decreasing of solar heat gain is among overriding considerations [6]. Despite being an integral part of a building, windows give an architect this opportunity to save energy by proper incorporation of windows [7].

With the growth in construction activities, it has become imperative that if design tools are to be provided, they can give insights into the sustainability of a building at an early design stage itself, and helps the design team to incorporate the sustainable solutions in a building initial design process.

The following context discusses in detail the roles of a window in the sustainability, specifically in the scope of energy efficiency and carbon emission.

## 2. Literature review

Along with the growing global trend in applying sustainability, Malaysia introduced its national sustainability assessment tool in 2010. Green Building Index (GBI) is Malaysia's industry recognized green rating tool for building to promote sustainability in the built environment. It is specifically developed for tropical climate, environmental and developmental context [8]. The major objectives of GBI include Energy Efficiency, Indoor Environmental Quality, Sustainable Site Planning & Management, Material and Resources, Water Efficiency and Innovation in which energy efficiency and material and resources comprise 32% of total marks in residential buildings in scale of 100. This shows the significance of modifying the conventional building construction and use of alternatives to enhance the efficiency in the building envelope.

Windows are important in the residential buildings for both energy consumption and carbon emission reasons. Good glazing design can reduce energy outputs by lowering the requirements for heating or cooling. Frame design can utilize more sustainable materials and those with lower embodied energy, such as timber and aluminium-clad timber. Windows are also important for the provision of daylight and a view, both of which have known psychological benefits. Although, glare and passive solar gain can be problematic, the life cycle energy consumption and thermal efficiency of windows can be improved through utilizing many alternatives. Among available options, those windows that use timber frames are considered more sustainable but those with materials such as aluminium and UPVC have higher embodied energy [2].

G.F. Menzies and J.R. Wherrett studied on four buildings to rate the comfort and sustainability level based on diverse types of multi-glazed windows by concentration on the energy using emphasizing the importance of architectural design on the multi-glazed windows performance [2]. Persson et al evaluated the different dimension of windows in terms of energy performance for low energy houses during winter

and summer by various orientations in Gothenburg. It was illustrated that by reduction in window area, there is a specific enhancement in winter performance energy [9].

Poirazis et al calculated the influence of glazing and surface and energy simulation in various directions for a large office building [10]. Eskin and Turkmen analyzed the effects of factors such as insulation, environmental condition, various windows and thermal transmittance for an office in four seasons in Turkey. It was inferred that window size and type impacts are vital for the cooling energy rate and peak load [11]. An analogy was drawn by Almeida Tavares and Oliveira Martins in order to investigate the approaches of designing a large office building concluded that there is no significance impact of triple glazing windows on energy efficiency and peak load [12].

As a similar result, Carrié et al scrutinized some methods to adopt energy performance rates and propose conservation approaches for a commercial building in Canada [13]. WERS (Window Energy Rating System) was established to formulate a particular framework in terms of total window and frame transmittance within two climatic zones in Spain by Urbikain and Sala [14]. Andrea Gasparella et al concluded that windows surface does not have a significant role in winter energy requirements but, on the other hand, solar transmittance is the most effective parameter which conducts the major needs for energy in both winter and summer [15].

G.M. Stavrakakis et al proposed an innovative approach to ameliorate sizes of windows for a naturally ventilated flat in terms of thermal comfort by virtue of artificial neural network which led to a suitable and desired architectural design of windows [16].

This paper aims at evaluating the impacts of windows on the energy efficiency and CO<sub>2</sub> foot print by alteration of its size (considering a range from 16% to 41% of window to floor area ratio), type (two double and two triple glazing), orientation of the principal windowed wall and filled gas (Argon and Air) of an insulated room designed in tropical climate of Malaysia (Fig.1).

### 3. Research methodology

The case study is a 56.25 m<sup>2</sup> single storey hut located in Kuala Lumpur which is modelled in Archicad 14 with conventional and well insulated materials. The next step is to list various window details of the building among which, the most commonly used multi glazed windows based on supply and demand, are to be chosen for simulation. Table 1 and 2 show the list of components used and their specifications. The simulation is carried out by Graphisoft EcoDesigner which is a new integrated sustainability assessment tool in Archicad. EcoDesigner uses the same simulation kernel as the VIP Energy product, which is validated by EN-15265, IEA-BESTEST and StruSoft-BESTEST.

Known parameters and values about all components are used for the calculation of a building's energy consumption. Climate factors like wind, temperature and humidity are taken into consideration for measuring the energy flow. Other parameters that play roles in the calculation are use of solar panels, requirements for room temperature, internal heat gains, air exchange, cooling system, heat pump and ventilation unit. Comparing the emitted energy is used in calculating the energy balance of the building.

The program calculates the energy balance of the building by comparing the emitted energy with the supplied energy. For the purpose of this study, 64 results were generated by the software. It is hypothesized that any incurred change in the windows has a direct impact on the energy loss and carbon emission in the building. Moreover, due to the tropical climatic situation of Kuala Lumpur, just one season and cooling required energy is taken into consideration in modelling and simulation. Furthermore, Hourly climatic data are calculated based on average monthly values; besides, the average temperature and cooling set point are respectively 27.5 °C and 22 °C.

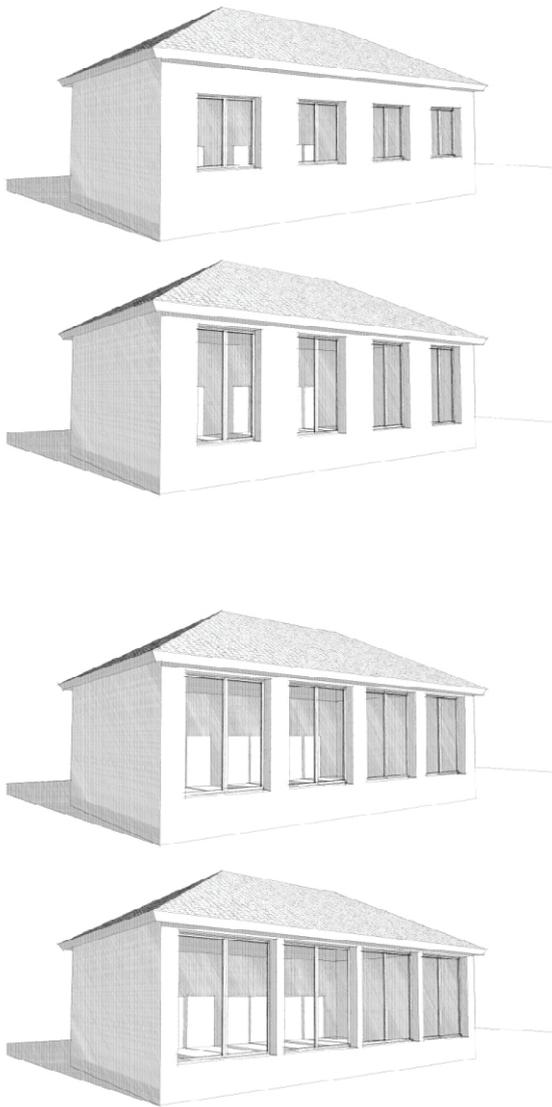


Fig. 1. The modelled building with four window alternatives, ranging from 16% to 41% window to floor area ratio.

Table 1. Windows' specifications

Window Type	Area				Glass %	U-Value	TST %	Infiltration
	16%	25%	34%	41%				
PVC 4-16-4 Clear Air	9 m <sup>2</sup>	14.1 m <sup>2</sup>	19.12 m <sup>2</sup>	23 m <sup>2</sup>	75	2.6	66	4.12
PVC 4-12-4-12-4 Coating Air	9 m <sup>2</sup>	14.1 m <sup>2</sup>	19.12 m <sup>2</sup>	23 m <sup>2</sup>	75	1.5	37	0.6
PVC 4-16-4 Clear Argon	9 m <sup>2</sup>	14.1 m <sup>2</sup>	19.12 m <sup>2</sup>	23 m <sup>2</sup>	75	2.5	66	1.59
PVC 4-12-4-12-4 Coating Argon	9 m <sup>2</sup>	14.1 m <sup>2</sup>	19.12 m <sup>2</sup>	23 m <sup>2</sup>	75	1.4	37	0.6

Table 2. Wall properties

Component	Skin	Thickness mm	Thermal Conductivity W/mK	Density kg/m <sup>3</sup>	Heat Capacity J/kgK	Area m <sup>2</sup>				Thickness mm	U-Value
						South	West	North	East		
Exterior wall	common Brick	103	0.58	1500	840	9.8	19.24	9.8	19.24	290	0.76
	Air Spapce	50	0.15	1.2	1008						
	Insulation	25	0.037	40	840						
	Concrete Block	100	0.6	1400	880						
	Plaster	12	0.57	1300	1000						
Roof	Roof Tile	35	1	2000	800		87.85			200	0.41
	Air Spapce	75	0.15	1.2	1008						
	Batt Insulation	75	0.037	40	840						
	Plaster	13	0.57	1300	1000						
Floor	Parquet	8	0.14	600	1700		56.25			360	0.88
	LWC	8	0.6	1400	880						
	Batt Insulation	8	0.037	40	840						
	Structural Concrete	12	2.3	2300	1000						

#### 4. Analysis and discussion

By a holistic view on the table 3, it can be seen that because of the small differences between U values of windows filled with Air and Argon, there is no significant variation of energy consumption and carbon footprint in terms of changing the filled gas. Therefore, to simplify the analysis, we focus on the differences in four sizes of windows filled with Argon gas.

In the case where the window to floor area ratio is 16%, the maximum and minimum amount of energy consumption for double glazed and triple glazed windows are respectively 10691 and 9584, 9929 and 9287 kWh. The difference in the consumed energy between the double glazing system and triple glazing system shows the merit of triple glazing system over double one which is more highlighted where the

windows are more exposed to direct sunlight as in this case; the East elevation compared to the North elevation. This is proven by 762 kWh of saving in the East compared to 297kWh in the North. Regarding to carbon footprint, the same trend exists among the divergent positioning of windows. As the windowed wall rotates from the North to the East, the amount of carbon footprint increases. This is due to the increase of energy consumption to cool the indoor environment as a consequence of more solar gain.

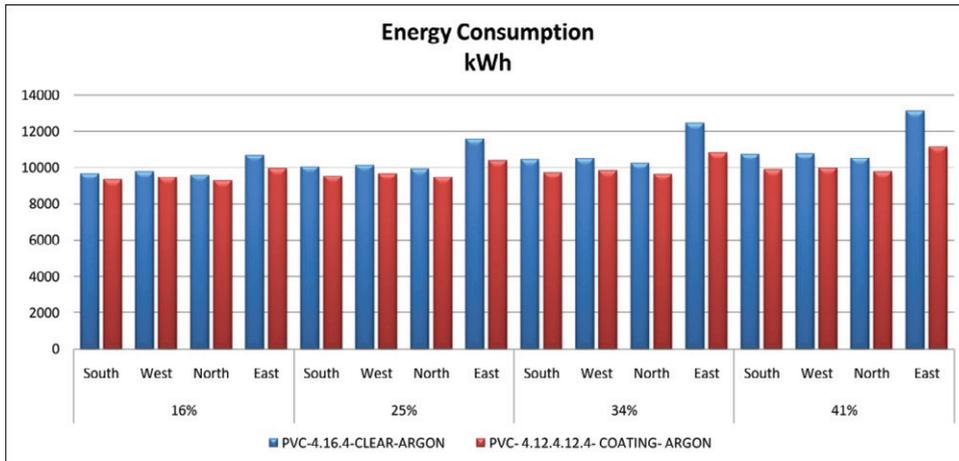


Fig. 2. Annual energy consumption for Argon filled windows

The application of three glazed systems reduces the thermal transmittance of the window by providing an extra insulating environment within glazes. Moreover, as the thickness of the window layers rises, the thermal conductivity drops consequently. This indicates that the windows ability to conduct heat has an inverse relationship to the thickness. For example in figure 3, once the ratio of window to floor is 25%, the energy consumption for triple and double glazed windows, when facing the East, are 10372 and 11562 kWh while windows viewing North are 9461 and 992 kWh. This illustrates the abatement energy usage and in line with energy saving, a reduction in the amount of carbon footprint is evident.

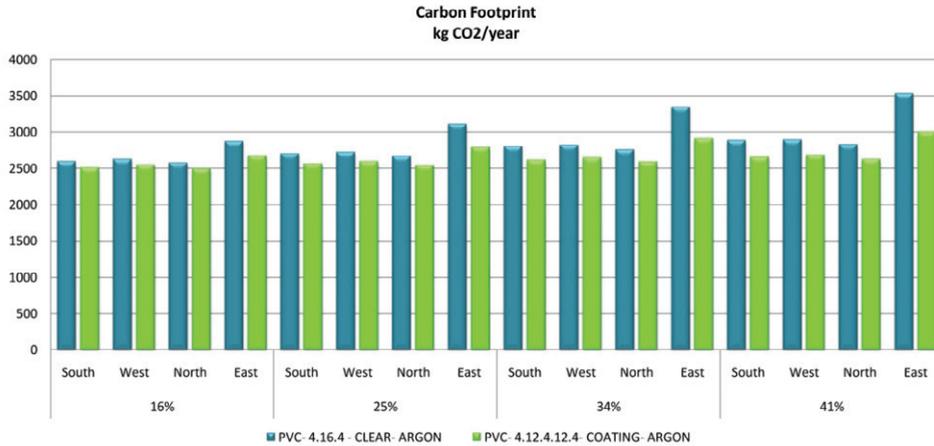


Fig. 3. Annual Carbon footprint for Argon filled windows

Where there is a material or substance (such as glass) between the sun and the objects struck that is more transparent to the shorter wavelengths than the longer, then when the sun is shining the net result is an increase in temperature. As the sizes of the windows increase, so does the amount of solar gain. Due to its direct relation to an area, thermal conductivity [W/K, m] is more in larger windows. This trend is clearly obvious in windows with the size of 34% of floor area compared to 25%. A 9% of increase in a double glazed window area in the East side results in 7.5% increase in energy consumption which is the same in the rate of the increase in carbon footprint in the preceding windows. Though enlarging the window surface leads to an escalation of energy consumption, but this slope from 34% to 41%, as depicted in figure 4, moves smoother in comparison with the priors. By contemplation on figure 4, it can be inducted that the increase in the rate of energy consumption with size variation between 16% to 34% does not correspond to the rate between 34% to 41%. The proportions of rises are 8.2% for 16% to 25%, 7.5% for 25% to 34% and finally 5.5% for 34% to 41% of windows to the floor area ratio.

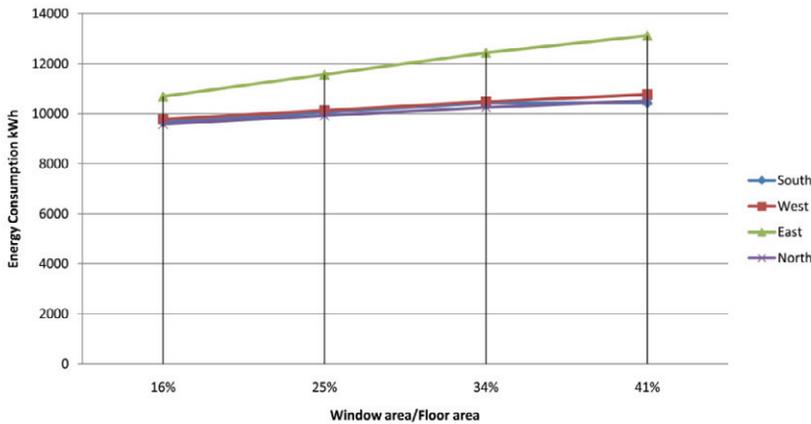


Fig. 4. Energy consumption rate in accordance with size

Table 3. Simulation Results

Code	Area %	Orination	Annual Energy kWh	Energy per m2 kWh/m2	Carbon footprint kg CO2/year	Code	Area %	Orination	Annual Energy kWh	Energy per m2 kWh/m2	Carbon footprint kg CO2/year
PVC 4-16-4 Clear Glass Air	16%	South	9673	171.96	2602	PVC 4-16-4 Clear Glass Argon	16%	South	9666	171.84	2600
		West	9778	173.83	2631			West	9772	173.72	2629
		North	9588	170.45	2579			North	9584	170.38	2578
		East	10694	190.12	2878			East	10691	190.06	2877
	25%	South	10060	178.84	2707		25%	South	10053	178.72	2705
		West	10139	180.25	2728			West	10131	180.11	2726
		North	9927	176.48	2671			North	9921	176.37	2669
		East	11577	205.81	3116			East	11568	205.65	3114
	34%	South	10446	185.71	2811		34%	South	10433	185.48	2808
		West	10495	186.58	2824			West	10486	186.42	2822
		North	10265	182.49	2762			North	10252	182.26	2759
		East	12448	221.3	3352			East	12437	221.1	3349
41%	South	10745	191.02	2892	41%	South	10730	190.76	2888		
	West	10771	191.48	2899		West	10768	191.43	2898		
	North	10527	187.15	2833		North	10522	187.06	2832		
	East	13124	233.32	3534		East	13120	233.24	3533		
PVC 4.12-4-12-4 Coating Air	16%	South	9336	165.97	2511	PVC 4.12-4-12-4 Coating Argon	16%	South	9332	165.9	2510
		West	9469	168.34	2547			West	9467	168.3	2547
		North	9294	165.23	2500			North	9287	165.1	2498
		East	9930	176.53	2672			East	9929	176.52	2671
	25%	South	9534	169.49	2565		25%	South	9528	169.39	2563
		West	9654	171.63	2597			West	9650	171.56	2596
		North	9467	168.3	2547			North	9461	168.2	2545
		East	10379	184.52	2793			East	10372	184.39	2791
	34%	South	9730	172.98	2618		34%	South	9722	172.84	2616
		West	9836	174.86	2646			West	9831	174.77	2645
		North	9638	171.34	2593			North	9632	171.24	2591
		East	10822	192.39	2913			East	10814	192.25	2910
41%	South	9881	175.66	2658	41%	South	9871	175.48	2656		
	West	9980	177.42	2685		West	9971	177.26	2683		
	North	9770	173.69	2628		North	9761	173.53	2626		
	East	11165	198.49	3005		East	11155	198.31	3002		

### 5. Conclusion

Designing a building entails considering a plethora of factors. In this competitive market, being able to make quick decisions and choosing the best option is considered as an advantage. With respect to project appraisal and the impact of sustainable criteria such as the energy consumption and carbon footprint on the design, BIM assessment software can aid the AEC group to collect the vital information from the model to analyze and select the most beneficial alternative in the early stages of the design.

Windows are important in the construction for both environmental and psychological reasons [17]. Well designed windows contribute to sustainability and green buildings by diminishing the content of

carbon emission and energy usage. This paper aims at the evaluation of modern multi-glazed windows which are common in industrial building systems and drawing an analogy among them regarding to their impacts on energy consumption and environmental issues such as carbon footprint.

According to the simulation results, the following points are highlighted:

The type of gas used in double and triple glazed windows does not have substantial impacts on the amount of energy consumption and carbon footprint in the tropical climate of the simulated building.

As a general rule, the East elevation in the building in this case study received the most amount of solar gain and placing the windows in that elevation with regard to thermal conductivity leads to more utilizing of the cooling system to compensate transmitted heat inside. As opposed to the East side, the North side receives the least amount of sunlight. Consequently, placing the windows in that elevation helps the building to maintain a cooler condition inside.

Among the various types of windows tested, #4-16-4 Air located in the East side by 41% of area of window to floor ratio with 13129 kWh and 3534 kg CO<sub>2</sub>/year is the worst alternative and #4-12-4-12-4 coating Argon located in the North side by 16% of area of window to floor ratio with 9287 kWh and 2498 kg CO<sub>2</sub>/year is the best choice.

According to the simulation results, the increase of the size of window to 41% does not differ significantly from 34% with regard to energy consumption in tropical areas. This suggests that in the cases where more natural lighting is desirable, using larger windows with the size of more than 34% to the floor area won't exacerbate the energy consumption.

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