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Analysis of Windows Element for Energy Saving in a Tropical Residential Buildings in Order to Reduce the Negative Environmental Impacts

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Abstract

In the contemporary milieu of today, sustainability and environmental concerns have become a great subject of debate. Matters related to sustainability are often linked to other crucial concerns like energy consumption. Energy is a key factor in ensuring continuous economic growth and development. One of the highest energy consuming systems in buildings – specifically residential homes in tropical regions – is the air conditioning system. Windows have been identified as the weakest link in the fabric of a building as they serve as thermal holes. Thus, the selection of proper window materials is crucial to reduce energy usage by minimizing the cooling and heating requirements of the building. The aims of this paper are analysis of energy performance for diverse types of window's glazing with different frames in order to find the most optimized window materials for the tropical residential buildings. The selected case study in this paper is modeled and then simulated by Building Information Modeling (BIM) application, which is appropriate for energy analysis. For simulation, some factors of the window materials were taken into consideration including, four physical properties of the U-factor, solar heat gain coefficient, visible transmittance, and emissivity. The result was shown windows types 02 and 03 were the most optimized of window materials and led to 10% energy saving into the base model and the windows type 05 was high U-factor, results in a greater transfer in internal zones and led to high energy consumption.

Keywords: Sustainability, Energy, Tropical countries, Residential buildings, Windows, BIM application

1 Introduction and Background

The past two decades had witnessed the parallel increase in energy usage and population growth, thus causing the incessant hike in energy prices as well as excessive emissions of CO2 and greenhouse gas (1,2). The International Energy Agency (IEA) had indicated a 48% hike in global energy intake in the last 20 years (3). The major increase in energy consumption has led to other critical issues including supply shortage, energy resource diminution, and grave environmental effects such as ozone depletion, climate change and global warming. Despite rising demands against the exploitation of energy and natural resources, environmental and sustainability concerns remain a leading global issue (4).

A number of critical issues related to the construction industry demand solutions in the form of global persistent efforts to change and adapt our actions to be more environmentally friendly. The construction of buildings require approximately 50% raw materials, 71% electricity intake and 16% water reserves while generating 40% landfill-bound wastes (5), all of which pose a heavy toll on the environment. The operations of buildings are also responsible for 50% carbon dioxide (CO2) emission and 18% indirect material usage and transferal (6). As a developing nation with rapid economic and technological growth, Malaysia is experiencing higher levels of energy intake than ever before. Figure 1 shows the overall trend of electricity usage in Malaysia over the past 18 years, with a significant surge from 53 Billion kWh in 2000 to the current 133 Billion kWh (7).

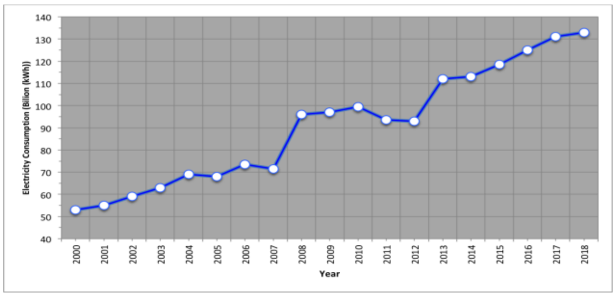

Figure1: Overall Electricity Consumption in Malaysia from 2000 to 2018 (7)

The highest energy intake comes from the building sector, which accounts for over one-thirds of the total energy intake and one-half of the total electricity usage globally (8). The IEA delineates energy efficiency as the "fuel" that reinforces the change towards establishing an energy system that is more sustainable. Along with this is the substantial untapped prospect of improving energy efficiency in the building sector to up to 80% (3). The rise in population is expected to increase the demands for building comfort and services including the need for higher energy consumption, parallel with the increase in the amount of time spent indoors. Energy consumption in the context of residential buildings in tropical regions is mainly contributed by the usage of air conditioning systems, which are used to control indoor temperatures and provide the occupants with thermal comfort. The aforesaid comfort is delineated as the "condition of mind that expresses satisfaction with the thermal environment" (4). Yu et al. (2009) highlighted a number of issues related to the usage of air conditioning systems. A majority of buildings in tropical regions have air conditioning units that run on electricity generated from primary energy sources including oil, coal, and natural gas. These sources release CO2 and greenhouse gases into the air; on a wide and prolonged scale, these emissions can deplete the ozone layer and cause grievous health risks for humans and other living beings. Therefore, reducing energy consumption for indoor cooling purposes can significantly help in energy conservation and environmental protection (9,10). In this context, sustainable strategies for residential buildings are capable of solving such problems i.e. by effectively controlling and reducing the amount and the ways of energy consumption and improvement of thermal comfort at the same time in residential buildings. Reducing energy consumption for indoor cooling purposes can substantially contribute to energy conservation and environmental protection (10).

The solutions offered by the Building Information Modelling (BIM) give architects and engineers the opportunity to come up with sustainable designs through the proper analysis, simulation and visualization of building performance. Energy simulation is a practical way for analysing various systems including the manufacturing system in a construction process (11). The Autodesk Revit and other BIM applications facilitate designers in designing, simulating, visualizing and collaborating on projects that can capitalize on the benefits offered by the interrelated data in the BIM model. Computer simulation also helps in analysing the energy usage in buildings. The amount of energy intake in buildings can be efficiently examined using BIM's simulation applications including Ecotect, EnergyPlus and Transys (12,13,14). EnergyPlus offers a broad and comprehensive simulation setting for the ephemeral simulation of various systems including buildings with multiple zones (15,16).

In terms of energy usage, the main consideration is on the materials required for the main components and envelope of the building. According to Sadeghifam et al. (2019), the energy intake for residential buildings in tropical areas can be significantly reduced by choosing the right components/materials for the ceiling, windows, walls, roof, and floor (4). A building would require high levels of cooling if the envelope has extreme heat transmission. The design for the building envelope includes the shell as well as the walls, floors, roofs, and windows (17). On average, thermal loss quantities in the country's prevailing residential buildings are: 35% for walls, 7.5% for floors, 7.5% for ceilings, and 50% for windows (18).

A properly designed glazing decreases the need for cooling and heating thus decreasing overall energy intake. The frame design could benefit from the use of sustainable materials as well as materials with the least possible embodied energy like timber and aluminium covered timber. Normally, windows are constructed at the front façade and the back, serving as natural lighting and ventilation outlets-inlets: heat from the sun can easily enter the indoor space and becomes trapped inside due to restricted openings (19). Hence, windows are crucial components of all buildings as they provide natural light and ventilation as well as protect against the weather. Nevertheless, windows have also been identified as thermal holes i.e. the weakest link in the fabrication of a building. They cause significant heat loss and thermal discomfort resulting from insulation properties such as the glass material that conducts heat. Hence, installing double-glazed windows can reduce energy loss via windows. The energy performance of windows can be determined by the window's properties and the location's climatic conditions (17).

In the past decade, many studies had been carried out in analysing the energy performance of windows according to their various properties (20, 21). G.F. Menzies and J.R. Wherrett examined four buildings and rated their levels of comfort and sustainability by looking at the various types of multi-glazed windows and their architectural design (22). Singh an Garg (2009) studied the effect of a building's floor, roofs, walls, and building zones in terms of their thermal transference capacity on the building's overall energy savings by looking at the different types of windows. The authors developed an equation for calculating the total amount of energy savings per window. They found that the energy saving capacity of a window relies on its type, the building's dimensions, the climate as well as the wall and roof's thermal transferral. The last two factors were found to save energy the most (23). Banihashemi et al. (2012) examined the capacity of double-glazed windows in reducing heating and cooling loads throughout a year of extremely cold weather. The authors found that the double-glazed windows in the aforementioned context cause extra cooling loads on buildings i.e. an outcome that is negligible when compared to the savings in heating load (24). Ihara et al. (2015) indicated that energy demand could be reduced by minimizing the solar heat gain coefficient and window U-value as well as increasing the solar reflectance of the opaque components (25). Meanwhile, He et al. (2019) studied 20 typical and prospective glazing alternatives in predicting possible energy savings in various buildings with similar orientations situated in various climate zones in China. Taking into consideration the multiple parameters and other elements, the authors found that the Low-E window glazing showcased the best energy performance for all the climate zones; however, it approximates traditional glazed windows in terms of energy savings capacity, which hinders its current adoption (26).

A holistic review of the previous literature and despite the public and governmental demands for energy-saving methods, there are rare investigations on the analysis of the potential window's glazing and frame alternatives together to investigate the potential energy savings for residential buildings in tropical countries. Therefore, the overarching aim of this study is to analyze the energy performance of potential windows alternatives (various types of window's glazing with different frames) in order to find the most optimize windows materials for the tropical humid climate residential buildings in Malaysia.

2 Case study

2.1 Location and climate

A case study of a double story building with one unit on each floor which was selected for simulation of duelling the conventional kind of residential building in Johor BahruJohor Bahru city is situated in south Malaysia, specifically latitude 1.48° N and longitude 103.73° E. The city is relatively humid (ranging between 82% and 86%) with high temperatures throughout the year. On average, it experiences dry-bulb temperature ranging between 21.9°C and 32.8°C, with monthly precipitations of 196 mm. Throughout the year, the city typically receives wind speed fluctuations of between 0 m/s and 5 m/s (calmly to moderately breezy), and occasionally goes beyond 7 m/s (Table 1).

Table 1: Climate data for Johor Bahru

Month	Jan	Feb	Mar	Apr	Jul	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
Average high °C (°F)	31.0 (87.8)	32.0 (89.6)	32.5 (90.5)	32.8 (91)	32.5 (90.5)	32.1 (89.8)	31.5 (88.7)	31.5 (88.7)	31.5 (88.7)	31.8 (89.2)	31.3 (88.3)	30.6 (87.1)	31.8 (89.2)
Average low °C (°F)	21.9 (71.4)	22.0 (71.6)	22.4 (72.3)	22.9 (73.2)	23.1 (73.6)	22.9 (73.2)	22.4 (72.3)	22.4 (72.3)	22.4 (72.3)	22.6 (72.7)	22.7 (72.9)	22.4 (72.3)	22.5 (72.5)
Average rainfall mm (inches)	162.6 (6.40)	139.8 (5.50)	203.4 (8.00)	232.8 (9.16)	215.3 (8.47)	148.1 (5.83)	177.0 (6.96)	185.9 (7.31)	190.8 (7.51)	217.7 (8.57)	237.6 (9.35)	244.5 (9.62)	2,355.5 92.736
Average raing days (≥1.0 mm)	11	9	13	15	15	12	13	13	13	16	17	15	162

2.2. Description of the case study buildings

As a scope limitation, the chosen building is assumed to represent the residential building constructed using commonly found materials in Malaysia. A case study is a double story building with one unit on each floor and each unit of this residential building has the main living space including the kitchen, living room, two bedrooms with their toilet, and bathroom along to corridor. The total area of the building is 152 m2 and the total windows area ratio to the total floor area is 10%. This house has two levels of similar designs that are divided into fourteen thermal zones, which have separate thermal properties on each level. The division of building in different zones in the simulated model is shown in (Figure 2).

Figure 2: The layout of building in separate zones in the simulation model

3 Research Methodology

Methodology wise, this study compared the physical specification alterations of the building's window components focusing on the simulated model's energy performance as analyzed by the BIM. The research scope was limited by assuming that the base model is a representation of a residential building constructed with commonly used window materials in the context of Malaysia.

Table 2: Component properties of simulated building

Component	Layer Name
Floor	Concrete (medium density) Cast concrete (Dense) (10 cm) + tile (1.2 cm)
External walls	Cement sand render (1.3 cm) + brick (22 cm) + gypsum plastering (1.3 cm)
Internal walls	Brick (11 cm) + inner/outer gypsum plastering (1.3 cm)
Window	Alum framed window, single glazing (6 mm)
Ceiling	Acoustic tile suspended (10 mm)
Roof	Wooden batons (20 cm) + air gap (10 cm) + clay tiles (3 cm)

3.1 Modelling of the Case Study

At this stage, the buildings in the selected case studies are modelled or simulated using the Autodesk Revit i.e. one of the most useful software in BIM for dynamic building simulation. In simulating the case buildings, CAD drawings were imported to Autodesk Revit entailing explicit parametric design features. Table 2 shows the characteristics of the materials used in the original model, which are important in establishing the energy consumption baseline of a standard house.

3.2 Energy Simulations and Analysis of the Case Study

This step is to simulate and analyze the model considering the energy factor. This step entails the simulation and analysis of the model taking into consideration the energy factor. Energy Plus i.e. a prominent software used in studies on energy analysis was chosen as the platform for measuring the cooling loads. Accurate analysis requires the usage of variables such as building type, building orientation, and climatic data for the building's location. The weather was simulated by referring to the weather report for Johor Bahru. Energy intake was simulated by considering each room in the building as a zone with distinct thermal properties. In this study, the building's model was separated into 7 zones for each level, each having its own set of specifications with respect to behaviour activity, HAVC systems, and comfort temperature. To ensure thermal comfort, the thermostat was fixed at 22 °C - 26 °C according to the ASHRAE standards. Both levels 1 and 2 use the same data as shown in Table 3 for level 1.

Table 3: Occupant Profiles for the different zones for each unit

Zone	Area (m²)	Activity	HAVC System	Comfort Band
Living Room	80	Sedentary	AC	22-26
Bedroom 1	24	Sedentary	AC	22-26
Bedroom 2	17	Sedentary	AC	22-26
Kitchen	16	Cooking	Natural ventilation	NA
Bathroom	3	Sedentary	None	NA
Toilet	6	Sedentary	None	NA
Corridor	6	Sedentary	AC	22-26

3.3 Energy Evaluation of the Window Alternatives

Finally, eight types of window glazing in various frames commonly used in residential buildings in Malaysia were selected to be compared (Table 4). For the simulation, attention was given on the physical properties of U-factor, solar heat gain coefficient (SHGC), visible transmittance (VT) and emissivity in the selection of the sample windows (27). The eight types of window materials utilized for the component were then tested. Next, based on the data analysis, the most optimized window materials were determined to be used in residential buildings in Malaysia. Table 4 shows the chosen window properties for simulation. In measuring the effect of the window types on the cooling loads, the properties of the other components i.e. walls, roofs and others were maintained whilst the simulations were conducted by changing the window properties. Lastly, all the simulations were carried out to determine the selected buildings' annual loads.

3 Results and Discussion

In order to analyze the energy consumption of the building used as a case study, a model was created in a BIM application. The case study as a base model was modelled by using the Autodesk Revit software and ready for energy simulation through EnergyPlus to calculate the cooling loads. The output of the Autodesk Revit software with scaled dimensions and its particular details are presented in Figure 3.

Table 4: Properties of selected windows for simulation

Window Type	U-Factor (W/m^2. K)	SHGC	VT	Emissivity
W-01	2.700	0.81	0.639	0.78
W-02	2.410	0.75	0.611	0.78
W-03	2.260	0.75	0.639	0.78
W-04	2.900	0.81	0.647	0.10
W-05	6.000	0.94	0.753	0.10
W-06	6.000	0.56	0.725	0
W-07	5.100	0.94	0.737	0
W-08	5.000	0.78	0.658	0

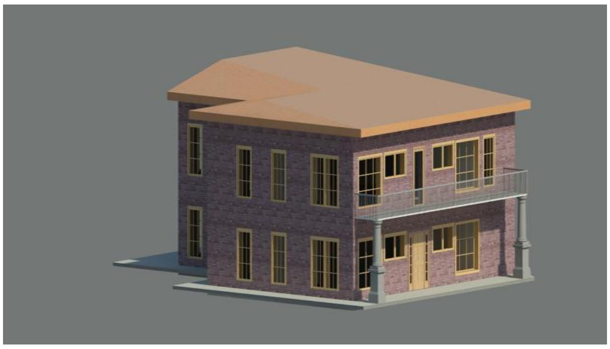

Figure 3: View of simulated building

As shown in Figure 4, the results of the energy analysis in EnergyPlus indicate the different levels of cooling load each month for the base simulated building with the existing materials. Figure 4 shows that energy consumption for cooling loads in May, Jun, and July were higher than the other months, which was indicated warmer weather during these three months. Meanwhile, energy consumptions (cooling loads) in November and December were the lowest at 1827.566 kWh and 1828.583 kWh respectively. According to the result, the cooling load was decreased from May to December and again was increased from February to May. It can be derived that there was a cooling load for all months of a year since the building was located in Malaysia where the climate is hot and humid. Consequently, the total annual cooling load of the building in this condition was found to be 23592.121 kWh, which results in 155.211 kWh/m^2.

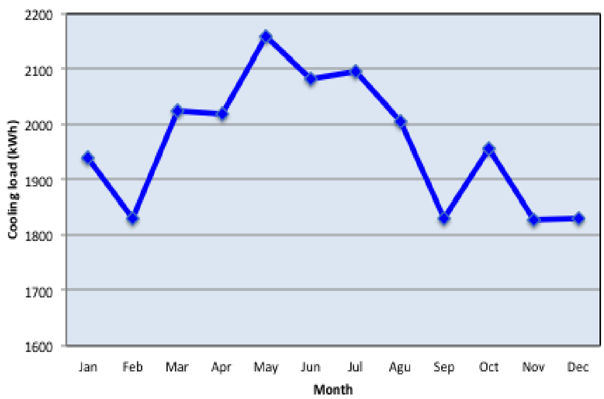

Figure 4: Annual energy usage (cooling load) of the case study

The thermal simulation was used in examining the performance of the eight window types focusing on the annual cooling load savings. The derived results were then compared to determine the most optimal window materials. The energy analysis results of the various window types are presented in Figure 5.

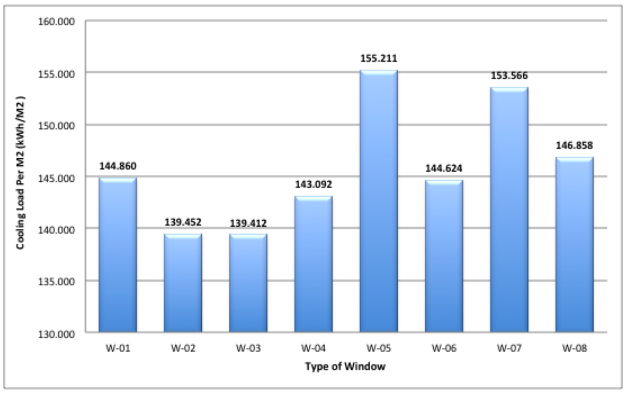

Figure 5: Impacts of different types of window on cooling load

The analysis of the simulated window alternatives (see Figure 5) shows that the highest energy saving was presented by W-02 and W-03, making both the most suitable window materials for energy saving. Table 5 shows that the energy-saving amount in cooling loads for W-03 (DoubleGlazed-Lowe-TimberFrame) and W-02 (DoubleGlazed-Lowe-AlumFrame) were around 10% with the lowest U-factor and SHGC. W-05 (SingleGlazed-AlumFrame) as base model demonstrated the highest U-factor and SHGC, indicating a higher heat transfer rate and thus the least savings rate. As the U-factor of all the windows showed a lower value than that of the base window, all the simulated windows are concluded to have a better performance than the base window, contributing a 1 to 10 percent savings in cooling load.

Table 5: Amount of energy saving for different types of window

Type of Window	Name of Window	Energy Saving	Rating of Energy Saving
W-01	DoubleGlazed-AlumFrame	6.67%	5
W-02	DoubleGlazed-Lowe-AlumFrame	10.15%	2
W-03	DoubleGlazed-Lowe-TimberFrame	10.17%	1
W-04	DoubleGlazed-TimberFrame	7.80%	3
W-05	SingleGlazed-AlumFrame	0%	8
W-06	SingleGlazed-AlumFrame-Blinds	6.82%	4
W-07	SingleGlazed-TimberFrame	1.05%	7
W-08	Translucent-Skylight	5.38%	6

In terms of the cooling load results, the other alternatives had outperformed the base window as demonstrated by the low U-factor that indicates a low transfer rate. Hence, the thermo physical properties are the mechanisms accountable for the heat transfer or storage in the buildings. The key thermo-physical property is the U-value, which identifies the heat transfer rate in and out of the structure and therefore the energy loads for air conditioning and heating (28). The U-value designates the total Watts utilized per hour in one-meter square of the building when the hot/cold temperature variance is at one degree Celsius (29).

Generally, the usage of windows with low U-factor can significantly result in cooling load savings owing to the substantial temperature gradient between the indoor and outdoor temperatures in a tropical environment. Hence, owing to the low U-factor value for all the windows in comparison to the base window (W-05), all the simulated windows recorded a better energy performance compared to the base window, contributing to cooling load savings of between 1 and 10 percent. The SHGC entails the amount of heat from the sun that enters via a window. A low SHGC indicates a low transmission of solar heat (17). A high SHGC denotes a high transmission of solar into a room resulting in the need for more energy to balance the cooling load. Additionally, the results indicate that the double-glazed low-E and double glazed lowers the annual cooling energy load percentage in comparison to the buildings that utilize standard glass. The results demonstrate that the double-glazed window contributes to more energy savings than the single-glazed window. In terms of frame design, more sustainable materials could be used such as Timber and Aluminium, which have low embodied energy.

4 Conclusions

A building's life cycle sustainability depends greatly on the earlier construction decisions made. Identifying weak segments and implementing alterations according to the attainable options facilitate the designer in reducing the negative environmental implications of the building and improving the green segments of the building. Therefore, the BIM applications could help develop more efficient and accurate manipulations and management of the design process. Building materials demonstrate diverse energy performance reactions according to the building's location, physical characteristics, and climatic condition. In this paper, the behaviour of windows materials with respect to saving energy for Johor Bahru city, which represents the hot and humid climate of Malaysia, was studied. 8 different window's glazings with different frames chosen from the market were used for comparison purposes. Analyzing the last suggested model of this study that included the aspects mentioned earlier to choose the most suitable materials for windows led to 10% energy saving in contrasting to the base model. Finally, it was found U-factor and SHGC are two main properties that play key roles in determining the energy performance of windows. Furthermore, it was concluded the merits of utilizing double glazed windows with minimum embodied energy like Timber and Aluminium frames lie in their savings in terms of cooling load.

Aknowledgment

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Ethical issue

Authors are aware of, and comply with, best practice in publication ethics specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests and compliance with policies on research ethics. Authors adhere to publication requirements that submitted work is original and has not been published elsewhere in any language.

Competing interests

The authors declare that there is no conflict of interest that would prejudice the impartiality of this scientific work.

Authors' contribution

All authors of this study have a complete contribution for data collection, data analyses and manuscript writing.

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