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ENERGY CONSUMPTION AND PAYBACK PERIOD ANALYSIS FOR ENERGY-EFFICIENT STRATEGIES IN GLASS TYPE OPTIONS

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ABSTRACT

Cities are facing a challenge with the steady increase in energy consumption for buildings. This study aims to analyse the energy consumption and payback period of energy-efficient strategy implementation in glass type options. The energy-efficient strategy in the glass options is chosen since it affects the energy consumption the most. A study on the payback period needs to be conducted since purchasing high-performance glass materials increase the building capital cost and become a consideration for decision-maker. This study tested 5 variations, including single and double glass windows and incorporating 5 types of glass materials with various solar transmittance properties. The energy consumption then is calculated using energy simulation software OpenStudio using Jakarta weather data. The payback period is calculated to find out the length of time the energy cost saving can recoup the additional capital cost needs to purchase better thermal performance glass. The result shows that the double glass windows with low solar transmittance value reduce the energy consumption for cooling the most. Thus, cheaper glass material with similar solar transmittance value reaches the payback period fastest.

Keywords: energy consumption, energy-efficient, glass type, payback period

INTRODUCTION

Cities in the world are facing the challenge of reducing energy consumption due to an increase in the use of electronic equipment (Kirimtat, 2016). Thus, energy-efficient strategies are essential to be implemented to tackle this issue. The increase in energy usage on air conditioning in tropical countries is unavoidable. Harkous et al. (2018) found that in humid equatorial climates, the overheating hours reach a height of about 81%. On the other hand, capital cost becomes the main burden of implementing energy-saving strategies in buildings.

External loads from the building envelope and internal loads from equipment, light, and occupant affect the total amount of building cooling loads. Windows, which commonly takes the large amount of building envelope, contribute to approximately 60% of the cooling load in office buildings in Jakarta (DKI Jakarta Province Govenment, 2012).

Windows are responsible for transmitting a high amount of unwanted solar heat gain. The selection of window glazing affects the thermal transfer and further adding the building cooling loads. Moreover, the window as one of the building components has a relatively long lifespan for 20-60 years before replacement (Scott, 2007). Purchasing high-performance windows reduce the building's total energy consumption cost, especially for cooling, which will be repaid the initial capital cost difference (Menzies & Wherrett, 2005).

Understanding of the payback period analysis of green buildings initiatives will increase the enthusiasm of the owners to invest more in the beginning. The additional capital cost will be offset by electricity cost savings after the payback period and continues to save more during building operational lifetime. The understanding of the payback period in decision-makers, increase the potential of energy-reduction decision trough architecture choice (Delgado et al., 2018).

This study aims to analyse the energy consumption and payback period of energy-efficient strategy implementation in glass type options. This strategy is important since the choice of glass type significantly influences the building energy consumption (Hassouneh, 2010).

Reducing the energy consumption can certainly be done by evaluating various architectural aspects. Glass type is proven to have a positive effect on reducing building energy consumption, one of which is by reducing solar transmission into buildings (Ozel, 2019).

Energy for cooling is responsible for approximately 55% of total energy use in office buildings in Jakarta (DKI Jakarta Province Govenment, 2012). The issue of high external gain usually arises due to the large proportion of window openings in high rise office buildings. Most of high-rise office building in Jakarta using curtain wall with the combination of the glass panel and aluminium frame as the building envelope.

The results of this study could propose the most optimal choice of glass material and construction combinations to be applied in the hot humid trpoic climate by taking weather data samples from Jakarta. Payback period time is used as the main criteria in determining the most optimal variation.

METHOD

This study tested 5 variations of windows, including single and double glass pane (Table 1) and incorporating 5 types of glass materials with various solar transmittance properties (Table 2). High-performance glass material commonly has a higher price, thus comparing the energy cost saving with additional capital cost becomes important to see that the performance offered worth the price. The variations tested chosen based on solar transmittance glass value which could affect the energy consumption significantly (Kaasalainen et al., 2020). Moreover, double glass and single glass pane also tested since it could affect the cooling load differently (Noh et al., 2017).

Table 1. Glass Type Variations

Variations	Glass Construction	Window Type
Base Design	Base Glass	Single Glass
V1	Glass A	Single Glass
V2	Glass B	Single Glass
V3	Glass A + Air Space 12 MM + Glass D	Double Glass
V4	Glass B + Air Space 12 MM + Glass D	Double Glass
V5	Glass C + Air Space 12 MM + Glass D	Double Glass

A simulation tool is used in this study for assessing energy consumption reduction from various glass options taking a case of an office building. The simulation programs have been used in scientific research and more preferred due to the easiness to control the fix variables such as space modelling, building envelopes and internal schedules. The accuracy to obtain energy calculation for cooling from filed measurement is found to be more complicated and harder to control due to the occupant behaviour (Yu, Du, & Pan, 2019).

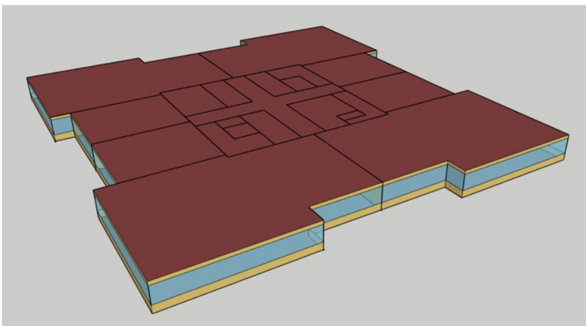

Figure 1. Base Design Model, Typical Floor of Office Building

(source: Author, 2020)

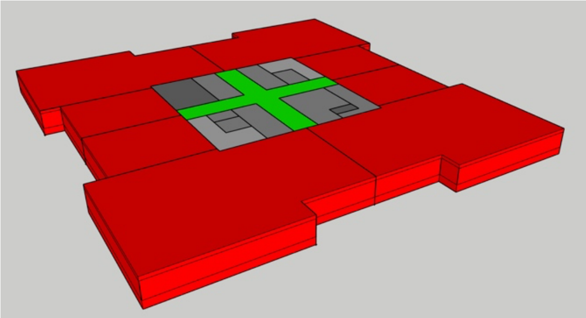

Figure 2. Base Design Model, Conditioned Zone: Open Office in Red and Internal Corridor in Green
(source: Author, 2020)

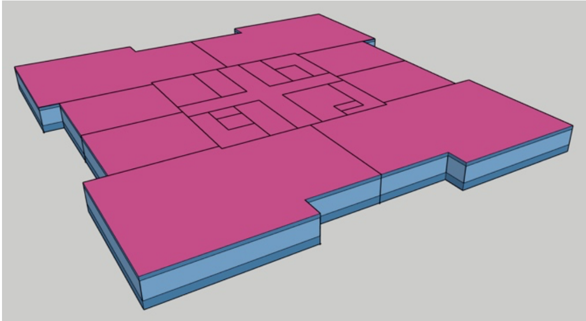

Figure 3. Base Design Model: Ceiling and Floor Set as Adiabatic
(source: Author, 2020)

Table 2. Glass Material Properties

Variations	**Base Glass** 3MM Clear Glass	**Glass A** 8MM Clear Reflective Glass	**Glass B** 8MM Dark Blue Reflective Glass	**Glass C** 8MM Low-e glass with inside coating	**Glass D** 5MM Clear Glass
Thickness	0.003	0.008	0.008	0.008	0.005
Solar Transmittance	0.837	0.59	0.27	0.22	0.81
Front Side Solar Reflectance	0.075	0.27	0.27	0.06	0.07
Back Side Solar Reflectance	0.075	0.23	0.1	0.27	0.07
Visible Transmittance	0.898	0.62	0.34	0.25	0.89
Front Side Visible Reflectance	0.081	0.35	0.35	0.05	0.08
Back Side Visible Reflectance	0.081	0.33	0.14	0.27	0.08
SHGC	0.87	0.62	0.39	0.35	0.83
U-Value (W/m2k)	5.9	5.7	5.7	4.1	5.8

Table 3. Electricity Cost Reduction

End Use Electricity	**Base Design**	**Variation 1**	**Variation 2**	**Variation 3**	**Variation 4**	**Variation 5**
Cooling	221,536.29	201,139.05	*185,566.82*	190,875.15	170,894.58	175,264.03
Interior Lighting	*67,027.83*	*67,027.83*	*67,027.83*	67,027.83	67,027.83	67,027.83
Interior Equipment	*63,444.50*	*63,444.50*	*63,444.50*	63,444.50	63,444.50	63,444.50
Fans	65,994.50	58,275.05	*53,705.60*	53,527.82	47,166.70	49,286.15
Total	418,003.11	389,886.42	369,744.74	374,875.30	348,533.61	355,022.51
Total/sqm	211.73	197.48	187.28	189.88	176.54	179.82
Electricity Reduction		**28,116.69**	***48,258.37***	**43,127.81**	**69,469.50**	**62,980.61**
Electricity Reduction from Base Design (%)		*6.73*	*11.54*	*10.32*	*16.62*	*15.07*
Electricity Cost Reduction* (USD)		**2,784**	**4,778**	**4,270**	**6,877**	**6,235**

*electricity price 1,467 Rupiah per kWh = USD 0.099 per kWh

Table 4. Additional Capital Cost and Payback Period

	Base Design	**Variation 1**	**Variation 2**	**Variation 3**	**Variation 4**	**Variation 5**
Glass Price (USD/m2)	**7**	**40**	**57**	**49**	**66**	**77**
Capital Cost* (USD)	**2,496**	**14,976**	**21,441**	**18,346**	**24,810**	**28,854**
Additional Capital Cost		**12,480**	**18,945**	**15,850**	**22,314**	**26,358**
Payback Period (years)		**4.48**	**3.97**	**3.71**	**3.24**	**4.23**

*Total building window area 374.4 m2

In this study, OpenStudio is used to model and generate the result in energy consumption analysis. OpenStudio is an energy performance software that takes EnergyPlus as the engine with a more user-friendly interface. The building modelling for base design and alternatives are built-in Sketchup using OpenStudio plugin. The energy simulation is conducted using Jakarta as the case location.

The simulation takes one level of the typical floor in an office building as the base model. The typical floor has 2,085.27 square meters in total, which consist of 1685.27 square meters of open office layout, 289 square meters of the internal corridor and 111 square meters of service core. The conditioned spaces include open office area and internal corridors (see Figure 2) with a 3-meter height from floor to ceiling.

As the building envelope, the model consists of external walls and external windows with window to wall ratio (WWR) set into 60%. The type of window used is a large window-wall which found to be the most preferred window type for an office building (Dogrusoy & Tureyen, 2007) with WWR 60% for higher occupant satisfaction (Hong et. Al., 2019).

The simulation only takes one level of a typical floor plan to reduce the simulation running time significantly. Partial simulation of building done by setting the external boundary for ceiling and floor as adiabatic because in the real condition the outside boundary of these constructions is connected to other floor levels thus no sun exposure nor wind affect the building from these parts. The area set into adiabatic for floor and ceiling construction coloured in violet (see Figure 3).

The simulation runs on five variations with single or double glass pane construction. The glass construction variations can be seen in Table 1. The glass variation is chosen based on the glass material properties. Glass A is an 8mm clear reflective glass, Glass B is an 8mm dark blue reflective glass, Glass C is an 8 mm Low-E inside coating glass and Glass D is a 6mm clear glass used as a combination in double glass construction.

RESULT

The simulation result shows the annual energy consumption, which mostly used for cooling. The comparison between electricity consumption in base design and the 5 alternatives of glass construction shown in Table 3. The electricity consumption of design variations then compared to its base design to get the electricity reduction.

It is shown in Table 3 that the electricity reduction varies from 6.73 % - 16.62 % in all variations. The highest electricity reduction happens in variation 4 and variation 5, which is a double glass window with low solar transmittance coefficient.

Furthermore, the electricity cost savings calculated based on electricity price in Indonesia, USD 0.99 per kWh, which result in approximately USD 28,000 – 69,400 saving annually for one typical floor.

Along with the electricity savings calculation, the additional capital cost for purchasing better performance glasses is estimated. The price is collected from one of the glass supplier companies in Indonesia in 2020. The price only calculates the glass pane without compromising the window frame and installation price. The price for glass construction variations is between 7 USD – 777 USD per meter square.

The payback period then calculated by dividing the additional capital cost that needs to purchase better glass performance with the electricity consumption cost savings (Table 4). The payback period varies from the minimum 3,24 years in variation 4 to 4.48 years in variation 1.

DISCUSSION

It is shown in figure 4 that variations of double glass windows have faster payback periods compare to single glass windows. However, implementing the highest performance glass material (Low-E glass) on double glass windows does not contribute to a significant reduction of payback period due to the striking difference in capital cost.

The most optimum glass construction variation for achieving the fastest payback period is in variation 4. Variation 4 using high-performance reflective glass with low solar transmittance coefficient. The low solar transmittance of variation 4 proofed to cut the electricity consumption for cooling more than other variations. Using low solar transmittance (low-g) window found to primarily control the energy efficiency of the windows (Kaasalainenet.al., 2020). This also results in the reduction of energy need for cooling, similar to adding shading elements.

High electricity reduction occurs in variation 4 and variation 5, which are double glass windows. Double glazing has a great impact on solar heat transmission, which lead to better energy performance (Aldawoud, 2017). Moreover, the average use of energy for cooling in a building using multi-layer glass proofed to be lower than in building using single glass if the percentage of the window is more than 50% (Noh et al., 2017).

As shown in Figure 5, a higher reduction in electricity consumption does not affect the payback period significantly. It caused by the higher price of high-performance glass material (Low-E).

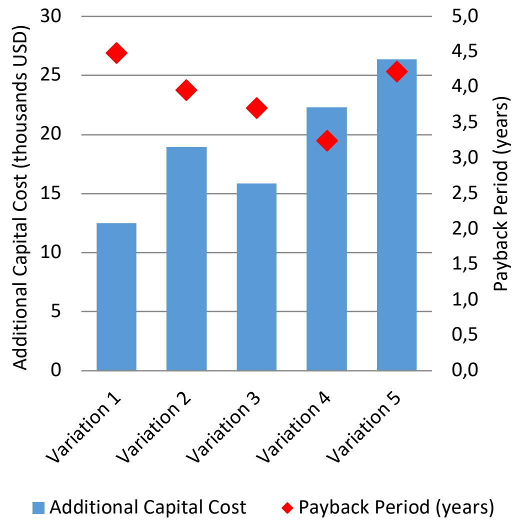

Figure 4. Comparison between Payback Period with Additional Capital Cost (source: Author, 2020)

Generally, the higher the additional capital cost for purchasing the glass, the more reduction in the electricity consumption for cooling. But there is a slight difference in variation 4 which the electricity reduction exceeds variation 5 with a less expensive capital cost. Variation 4 and variation 5 have similar solar transmittance coefficient. However, the reflective glass used in variation 4 is cheaper than the Low-E glass used in variation 5.

Window selection as part of a building component affects the total amount of energy used in the building. Office building commonly has glazing material applied to the building envelope massively. A large amount of wall area penetrates the daylight more optimal and increase occupant satisfaction (Hong et. Al., 2019). Thus, the application of low solar transmittance glazing becomes important since large size windows cannot be avoided.

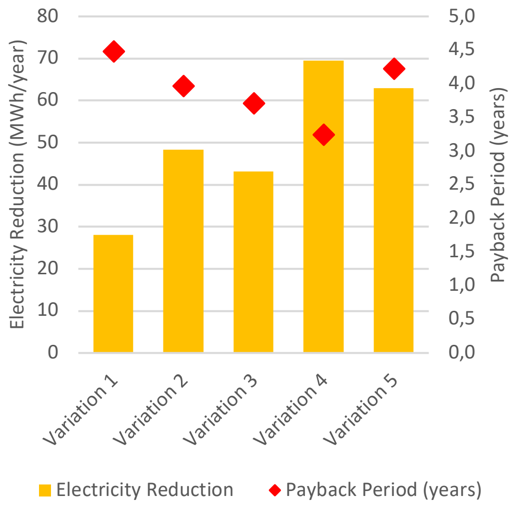

Figure 5. Comparison between Payback Period with Electricity Reduction (source: Author, 2020)

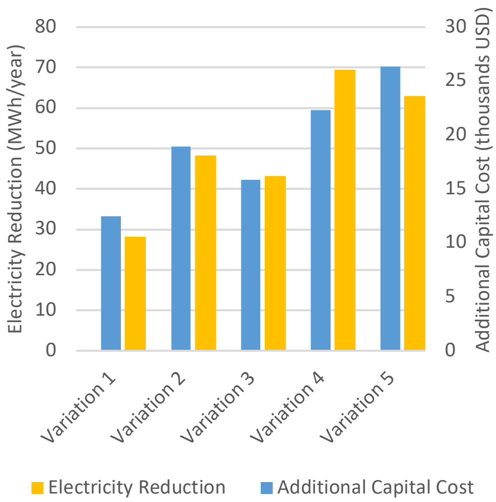

Figure 6. Comparison between Additional Capital Cost and Electricity Reduction (source: Author, 2020)

Low solar transmittance glazing proofed to increase the amount of electricity reduction and double glass system even reduce electricity consumption more.

Financial payback period where operational cost saving is calculated to recoup the capital cost of the energy-efficient strategy can be reduced by choosing the most optimum material in reducing the energy consumption with the lowest price.

CONCLUSION

The fastest payback period can be obtained by using the double glass window with low solar transmittance glass. This window specification is significantly reducing the electricity consumption, especially for cooling, while coupled with the lower capital cost then considerably reduces the payback period of the glass material even faster. Solar transmittance value is an indicator that can be used to predict the decrease in energy consumption when comparing different glass materials. Thus, cheaper glass material with the same solar transmittance value will provide a faster payback period.

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