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Increasing energy efficiency by considering building's life cycle

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Abstract. Greenhouse gas and carbon emission have a considerable impact on the people behavior on constructing new buildings. One of the attempt to combat environmental issues is by implementing renewable energy such as photovoltaics (PV) into the buildings. However, a high cost from sustainability concept makes building owners or investors hesitate to use the device. The research aims to evaluate the solar energy implementation by taking university library building as the case study. Due to space and cost aspects, the analysis only considers lighting system. The life cycle cost is used to generate the best alternatives to the building. The results show three potential options; alternative one use public electricity from state-owned enterprises in the energy sector with a fluorescent lamp, alternative two use PV with a fluorescent lamp and alternative three use PV with LED lamp. Alternative three recommends as the most potential implementation on the building as it generates lower initial cost, moderate cost of operation and maintenance as well as fair salvage value.

1. Introduction

Environmental issues become a significant topic during the last decades due to the increased of world's carbon emissions and greenhouse gas effect [1, 2]. Reference [3] estimates an increasing percentage about 23.85% volume of carbon emissions during 2000 to 2013. Many researchers and academics believed that human activities significantly contribute to the global warming [4, 5]. The building sector is one of the largest contributors by fifty percent to the world's carbon dioxide (CO₂) emission [3].

Office in Indonesia, for instance, needs a 15.2 million GWh to power the electricity or equal to 250 kWh per square meter. It is relatively higher than neighboring countries or any other developed countries with only 100 kWh [3]. Besides high energy consumption, many buildings still use non-renewable energy to meet the energy needs. On the other hand, solar power has the potential for development as it is environmentally friendly, produce insignificant pollution, and available during most of the time in developing countries such as Indonesia [6, 7].

Universitas Indonesia as one of the oldest and the largest university in Indonesia attempt to be a leader in implementing the sustainable concept in its building. The university built the main library that aims as a meeting point for students, lecturer, and many others to conduct research, discussion, and knowledge dissemination. The design attempt partial concept of sustainability from structural, vegetation, roof to the cooling system. High investment argues as one of the most significant factors that hinder the use of alternative energy in the building. Components are mostly imported from other



countries [8]. Thus, the renewable energy device has a low impact on the financial and economic aspects of the building. Considering those problems, the research will evaluate the solar energy implementation to the university's library building. The result recommends the best alternative towards energy efficiency in the public construction sector.

2. Methodology

The research uses a life-cycle cost (LCC) to evaluate energy usage. The LCC measurement is an economic evaluation method aims to determine the economic impact of alternative building designs and building systems expressed by nominal value or currency [9, 10, 11]. The factors in LCC categorized into the initial cost (purchase, acquisition, cost construction), fuel cost, operational, maintenance, and repair cost, replacement cost, residual value or salvage value or disposal cost, finance charges (loan interest payment and non-monetary benefit).

The measurement of Life Cycle Cost system is as follows [12]:

$$\text{LCC} = I + \text{Repl} - \text{Res} + E + W + \text{OM \& R} + O$$

Where,

LCC = Total cost

I = investment cost

Repl = replacement cost

Res = residual cost

E = energy cost

W = water cost

OM & R = operational and maintenance cost, residual

O = other costs

The case study was conducted in 2011 and involved a series of interviews with general contractors in Indonesia.

3. Result and Discussion

The preliminary calculation considers the power needs of Universitas Indonesia's Library Building. Interviews from general contractors show that it reached three mW. The number considers huge accommodated only by the photovoltaics (PV) regarding space and cost. Thus, the study will evaluate the lighting system to substitute for the PV system.

PV calculated by multiplied power over the duration of use. It is assumed lighting standby for about eight hours from nine in the morning to five in the afternoon. The PV considers watt/peak measurement for analysis. Three alternatives are generated for analysis, firstly is the condition where all lighting will use the public electricity from state-owned enterprise in energy. Secondly, all lighting use PV system by assuming 50% of the lighting is on at daylight. Thirdly, the lighting is replaced by LED system to reduce the energy consumption of the building.

The building has six floors with a different capacity of lighting on each floor. The first floor has 50,900 watts. Meanwhile other has 69,745 watts, 41,724 watts, 40,501 watts, 6,589 watts and 6,645 watts respectively. Thus, the total power for building lighting is about 216,304 watts or 216 kW. As the lighting only used 50%, the daily usage per day is about 108 kW. The government of Indonesia issued electricity tariff per month about 800 rupiahs per kWh for usage past the peak load time and a coefficient of 1.5 multiplied by 800 rupiahs for usage in peak load time. The amount of usage past the peak load time is 40%, or equal to 10,368 kWh/month, Peak Load Time about 15,552 kWh/month. The total electricity bill per month estimated for 26,956,800 rupiahs.

The cost of maintenance, repair, and operation is 14,176,817 rupiahs per year. The cost of maintenance and repair for solar panels and inverters is about 4,828,404 rupiahs per annum including personnel, utility, land lease and labor management. Assumption for LCC calculation considers the inflation (4.66%), discount rate (9.25%), reinvestment rate (4.66%). Escalation factors also involved in

the analysis of routine annual operation and maintenance, major repair/replacements, utility electric rate escalation, demand rate escalation, natural gas price escalation, photovoltaic degradation factor per year. All rate for escalation factors is about 4.66%.

3.1. *Alternative 1*

Option 1 use public electricity from state-owned enterprises in the energy sector. The lighting of Universitas Indonesia's public library uses the fluorescent lamp type. Investment costs consist of design costs, construction, and installation costs, material and equipment costs, indirect costs and contingency costs.

The investment cost is about 14,176,817,392 rupiahs; this cost includes construction and installation as well as the cost of material and equipment. The design cost is not taken into account as includes on the planning stage. Indirect cost assumed 5% from the investment cost as about 708,840,869 rupiahs, and contingency fee is 3% or equal to 425,304,521 rupiahs. Overall the total cost of investment and capital replacement in alternative 1 is about 15,310,962,783 rupiahs.

Annual expense on the project includes energy costs, operational costs, maintenance and repair and residual value and reinvestment. Energy cost derived from the use of electricity that requires 10,800,728,304 rupiahs per year. Maintenance and repair costs delivered from lamp usage and electricity installation both needs 3,344,938,167 rupiahs and 473,349,807 respectively.

Based on the interview, fluorescent lamp last for 5,000 hours. Lamp purchasing is about eleven times during twenty years of operation by assuming it used for eight hours per day. Thus, reinvestment for the lamp is about 195,901,100 rupiahs. Last, the salvage value calculated 10% from the investment period. Overall, the investment cost for the alternative 1 is about 15.31 billion rupiahs with 14.62 billion of operation and maintenance costs and 1.53 billion of salvage value.

3.2. *Alternative 2*

Option 2 combines PV with fluorescent lamp type for the analysis. An in-depth interview with local suppliers generates PV price and capacity for each panel of PV. One square meter of PV panel produces a 160-watt peak with a cost about US\$4 or equal to 8,561 rupiahs. Compared to the regular calculation of electricity, the PV estimates energy usage for the building. The calculation will determine the required PV panel for the building. The construction and installation are similar to the previous alternative as about 14,176,817,392 rupiahs. Meanwhile, the material and equipment are much higher than option 1. The PV requires 31,247,756,183 rupiahs with tripled times of indirect costs and contingency. The three components lead to a higher investment cost about 49,058,539,461 rupiahs or three times greater than the alternative one about 15,310,962,783 rupiahs.

Unlike the alternative one that used public electricity, in the option 2, energy cost is no longer involved due to replace by the PV system. Maintenance and repair cost should be generated from primary data in Indonesia by taking into account the differences in weather, location, installation, and location. However, due to data limitations, a benchmarking from Electric Power Research Institute (EPRI) is used. They calculate rule of thumb for maintenance and repair cost for about US\$ 47 per month or equal to 4,828,404 per year.

The electricity and lamp have similar cost with alternative 1. Maintenance and repair cost produce slight higher cost with 3,979,503,573 rupiahs. On the other hand, option 2 generates ten times greater salvage value compared to the previous option with 15,698,732,628 rupiahs over 1,531,096,278. Consequently, the investment cost for the option 2 is about 49.06 billion rupiahs with 3.98 billion of operation and maintenance costs and 15.70 billion of salvage value.

3.3. *Alternative 3*

Alternative 3 replace the fluorescent lamp with Light Emitter Diode (LED) lamp. It argues can reduce the energy usage nearly 50%. The replacement shall reduce the building energy usage from 108,152 watts per day to 62,818 watts per day. The PV investment costs from this replacement lowering the cost into 38,335,154,422 rupiahs. The construction and installation are similar with alternative 1 and alternative 2 for about 14,176,817,392 rupiahs. On the other hand, the initial cost of PV, as well as indirect and contingency costs are lower than alternative two but still higher than alternative 1. PV is

half the cost from alternative 2. Meanwhile, indirect and contingency is also half the cost of alternative two but twice the cost of alternative 1.

Despite generate lower investment cost compared to the alternative 2, the maintenance and repair cost in the alternative 3 three times higher than alternative 1 and alternative 2. It because the LED lamp requires more maintenance and repair cost about 9,698,641,328 rupiahs or the highest cost among other alternatives. In general, the investment cost for the option 3 is about 38.33 billion rupiahs with 10.33 billion of operation and maintenance costs and 12.27 billion of salvage value.

3.4. Comparison of Each Alternative

Initial cost for PV systems is higher than using public electricity. As a comparison, the initial cost for both alternative 2 and alternative 3 is almost triple times from the alternative one that uses public electricity. However, the PV generates lower operation and maintenance cost and higher salvage value by ten times greater. On the other hand, LED initial cost over fluorescents lamp shows a little gap. However, LED needs higher maintenance and repair almost seven times over fluorescents lamp. The analysis recommends alternative three as the most potential implementation to the building. It generates lower initial cost, a moderate cost of operation and maintenance as well as fair salvage value for the end of building's life cycle. The comparison among three alternatives can be seen in figure 1.

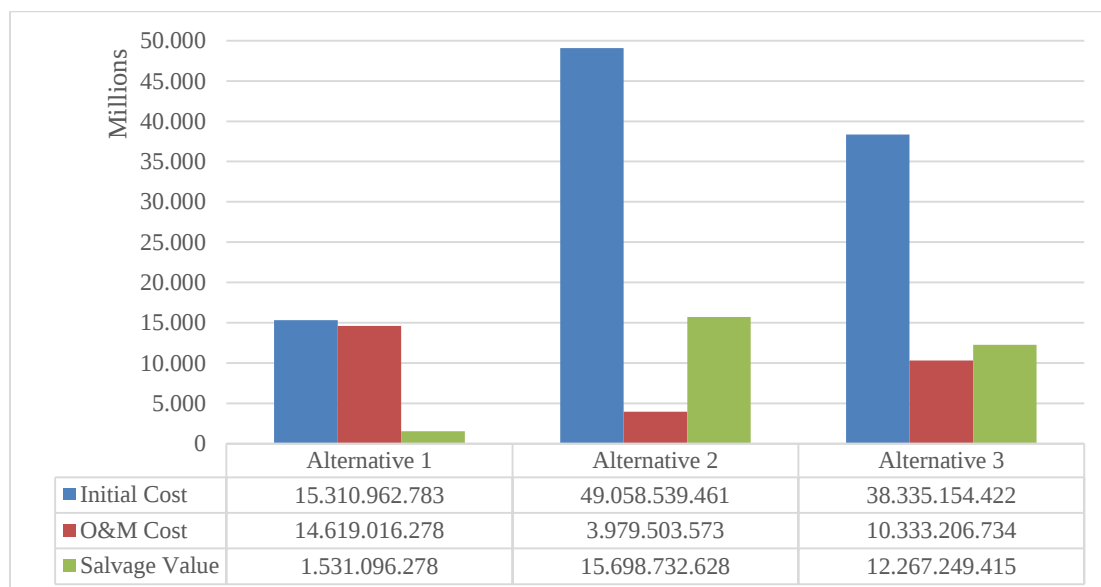


Figure 1. A comparison of LCC for each alternative.

From the analysis, the initial cost for PV is relatively high in Indonesia about the US \$ 10 per watt. Meanwhile, other countries have much lower price such as the United States, and Europe is about the US \$ 3-4 per watt, India to US\$ 2.80 and China about the US \$ 2.50. Indonesia has a high price due to the country ability that unable to produce PV panels in the domestic market. Other countries attempt to reduce the high initial cost by implementing strategic policy related to renewable energy such as tax incentives, tax credits, and subsidies on the use of renewable energy. Similar policy and regulation should be further evaluated related to energy in building in Indonesia. It is expected that renewable energy contributes to reduce world's gas emissions and provide clean energy for better living.

4. Conclusion

Buildings sector recommends using renewable energy to combat global carbon emissions and greenhouse gas effect. Universitas Indonesia library building attempt to operate sustainability concept by implementing photovoltaics (PV) to the building. However, due to space and cost aspects, only the lighting system may be evaluated.

The case study compares three alternatives; alternative one use public electricity from state-owned enterprises in the energy sector with a fluorescent lamp, alternative two use PV with a fluorescent lamp and alternative three use PV with LED lamp. The result shows that the lowest initial cost is alternative one followed by alternative 3 and alternative 2. Regarding the lowest operation and maintenance cost is alternative two followed by alternative 1 and alternative 3. On the other hand, salvage value for alternative 2 is the highest compared to alternative 1 and alternative 3. The result recommends alternative three as the most potential implementation on the building by considering lower initial cost, moderate cost of operation and maintenance as well as adequate salvage value.

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