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Research Article

Life Cycle Cost Comparison Study of PV and Concrete Rooftop in Jakarta

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This paper presents a comparative study of "life cycle cost" or LCC of a building school rooftop element in Jakarta. The simulation applied two different types of roof: a concrete roof and a PV rooftop. The aim of this study is to investigate the electricity production of the solar panels, the saving to investment ratio or SIR, and the total life cycle cost of each rooftop element. To accommodate those objectives, the calculation utilized a software called "Building Life Cycle Cost (BLCC) version 5" which is a product of the US Department of Energy. The simulation results showed that the LCC can be improved by 27.6%, and the "discounted payback" is reached at year 15. Indeed, this indicates that a roof made of solar panels is promising to replace the existing concrete roof.

1. Introduction

Sustainable development has been proclaimed for decades, and one of the goals is the use of alternative energy as an alternative source of electricity to replace the use of fossil fuel. In correlation to that, the report of the "Indonesian Energy Outlook 2012" states that a future building is expected to use alternative energy as a source of electricity by a minimum of 5% from the whole building energy usage. One of the most promising alternative energies according to the Indonesian Ministry of Energy and Mineral Resources is solar energy (Table 1).

However, the application of solar energy in Indonesia is still in its early stages. Essentially, there are several considerations in applying this technology; one of them is the high initial cost of the installation.

There are little studies on the economic factors in the application of solar energy in Indonesia, particularly the life cycle cost of a PV system. This study, therefore, focused on investigating the improvement of life cycle cost of a rooftop by replacing the current concrete rooftop with solar panels.

Life cycle cost or LCC is a method of an estimated economic cost calculation that focuses on all resources used by a project during its lifetime [1]. Additionally, according to Hin and Zmeureanu [2], the LCC includes operating and maintenance cost, initial investment, replacement, and disposal cost, so that it calculates current and predicted future cost. There are two parameters to estimate the future cost; they are net present value and internal rate of return. The internal rate of return is a discount rate that makes the net present value (NPV) of all cash flows from a particular project equal to zero. And as stated by Spertino et al. [3], the NPV and the internal rate of return are used to compare various alternative investments.

The purpose of this life cycle cost study can be listed as follows: (1) to simulate the electricity production of the PV rooftop, (2) to compare the life cycle cost between the concrete roof and the PV rooftop, (3) to study the saving to investment ratio when using solar panels as the rooftop, and (4) to conduct a study of the implications of the initial cost of using solar cells as compared to concrete roofs.

In order to fulfill the objectives, a calculation and comparative analysis of life cycle cost between a roof using solar panel and a concrete roof were conducted using Building Life Cycle Cost (BLCC) version 5 software. The software is a product of the Department of Energy, USA. The Bina Nusantara campus building was selected as the case study. The building is located in Jakarta, Indonesia.

Table 1: Comparison of energy power potential.

Type of renewable energy	Power source	Expected production
Geothermal	29.614 MW	1.341 MW
Hydro	75.000 MW	6.848 MW
Biomass	49,810 MW	1644 MW
Solar	4.8 kWh/m2/day	22.45 MW
Wind	3–6 m/s	1.87 MW
Ocean	49 GW	0.01 MW
Oil	7408 billion barrels	0.314 billion barrels
Natural gas	150 TCF	2.98 CF
Coal	161 billion tons	0.317 billion tons

Source: Indonesia Energy Outlook 2013, Ministry of Energy and Mineral Resources.

2. The Profile of the Case Study

The Bina Nusantara campus building has a coordinate position of 6°12′6.54″ S for the latitude position and 106°46′54.87″ E for the position of the longitude, and the orientation of the building is about 80 degrees of the north (Figure 1).

The area of the building is around 6650 m^2 and is divided into two main buildings, the lecture building and the parking building. The solar panel was only simulated over the lecture building which has an area of around 4900 m^2.

3. Simulation Method

3.1. Orientation of Solar Panels. In order to know the optimum orientation of the solar panel to obtain maximum sunlight, Ecotect software was used. The simulation results can be seen in Figure 2 and show that the region of Jakarta has maximum sunlight at the point of 77.5 degrees from the north direction.

3.2. Heat Transfer Model. The heat transfer method used in this study, particularly in defining the cell temperature, was the "decoupled" method. The decoupled method essentially is divided into two methods of condition. First is based on the nominal operating temperature condition (NOCT) and second is based on dynamic condition. The NOCT method in estimating the cell temperature at each time step is based on the method from Duffie and Beckman (1991). The method assumes the simulated environment with the wind speed of 1 m/s, the solar radiation of 800 W/m^2, the ambient temperature of 20°C, and no electrical load and a certain specified insolation. In this method, the input data of "module heat capacity" and "module heat loss coefficient" are not considered and the detailed equation is as follows:

$$T_c = T_a + \frac{(1 - (\eta_c/\tau\alpha))}{(G_T(\tau\alpha/U_L))}, \quad (1)$$

where T_c is the cell temperature, T_a is the ambient temperature, η_c is the cell efficiency which varies with the ambient condition, G_T is the total radiation incident of the PV array,

Figure 1: The location of Bina Nusantara University building.

U_L is the array thermal loss coefficient, and $\tau\alpha$ is the user defined constant. Based on 1, therefore, the cell temperature is only influenced by the cell efficiency that varies with the ambient condition. As for the other method, namely, "Decoupled Ulleberg Dynamic", the cell temperature is defined by a function of the previous cell temperature and the thermal capacity of the PV module (C). It can be seen from the equation below that is developed by Ulleberg:

$$T_{\text{cell}}\big|_t = T_{\text{ambient}} + \left(T_{\text{cell}}\big|_{t-1} - T_{\text{ambient}}\right) * e^{(-UL/\text{cap})\Delta t}. \quad (2)$$

Since the simulation was assumed to be conducted in a more real condition, therefore, the study used the second method.

3.3. Simulation

3.3.1. Electricity Production. The simulation was conducted in EnergyPlus version 8.0. The geometry of the building was built on Google Sketchup where OpenStudio software had been integrated to allow visualization of the selected building. Solar panels with monocrystalline silicone technology was used in the simulation, with the following technical specifications: (1) the watt peak was 240 watts, (2) the efficiency of the module was 21.6%, (3) the temperature coefficient was −0.3%/°K, and (4) the panel dimension was 1580 × 798 × 35 mm which consists of 72 cells. Based on the previous research, to maximize the work of solar panels, the selected roof was flat shaped (flat roof) with 10-degree angle from the horizontal line (see Figure 3) [4].

3.3.2. Building Life Cycle Cost. As explained earlier, this study applies a software called Building Life Cycle Cost (BLCC) version 5. This software is particularly useful for analyzing and predicting the "cost" and benefits of energy conservation-oriented projects. In addition, another advantage of using this software is that it can evaluate two or three alternative systems to see the lowest life cycle cost. The aspects required for the calculation are as follows: (1) the "energy cost" and (2) the "capital component" which includes (a) investment cost, (b) replacement cost, and (c) operating, maintenance, and repairs, including annually and nonannually recurring costs. The calculation also needs cost parameters such as: (1) service life, (2) inflation rate and (3) discount rate. The concept of analysis of this study can be seen in Figure 4.

3.4. Energy Cost. The "energy cost" here is determined by the production of electricity generated by solar panels and then multiplied by the price of electricity per kilowatt hour (kWh) of the local State Electricity Company. The price of electricity inputted into the simulation system was assumed

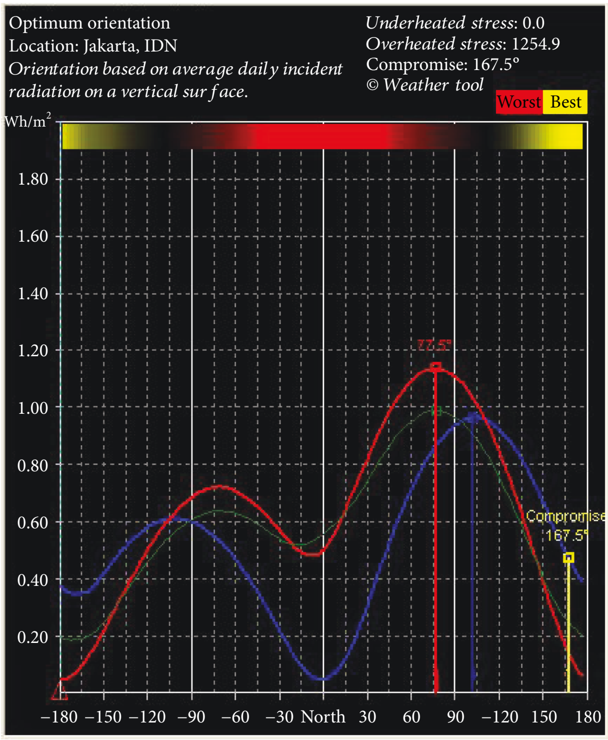

FIGURE 2: The direction of most sunlight throughout the year. Source: Weather Tool

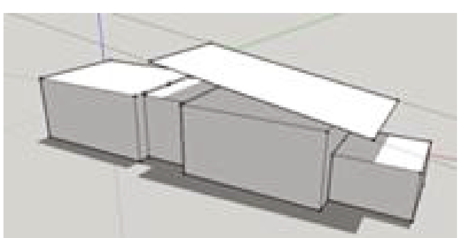

FIGURE 3: Flat roof form made of solar panels. Source: [4].

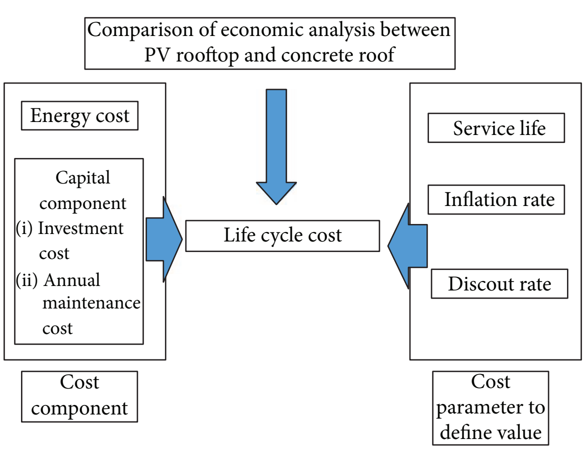

FIGURE 4: Analysis approach.

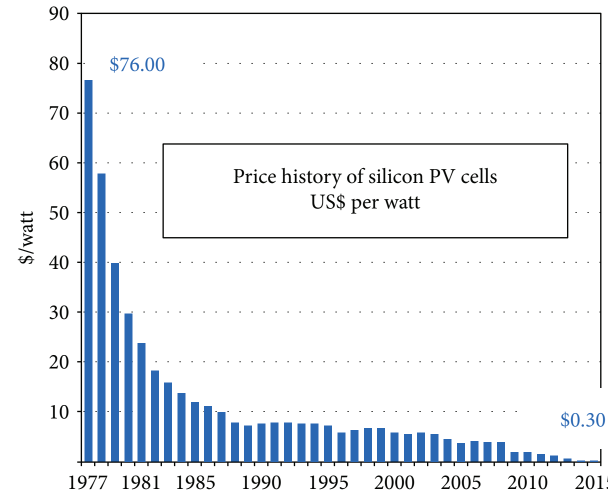

FIGURE 5: Graph of the development of the price of solar panels per watt peak. Source: https://commons.wikimedia.org/wiki/File:Price_history_of_silicon_PV_cells_since_1977.svg.

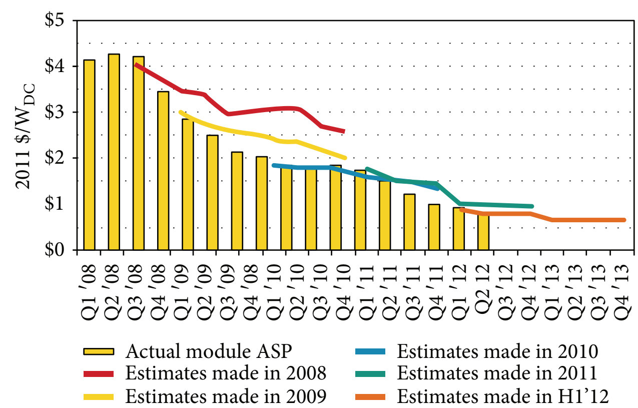

FIGURE 6: Approximate prices according to the average actual prices on the market analysts. Source: Department of Energy, USA, 2012.

to be IDR 1250.59. This price was for a customer that has electrical usage above 200 kVA, and as for the solar panels, the price was based on the specifications of solar panels, in particular was the watt peak. Figure 5 shows the price trend of solar panels per watt peak from 1997 to 2015. It can be seen that the retail price of solar panels declined considerably of about 50% over a period of 9 years, and this is quite promising for further developments.

Furthermore, the declined price of the solar panel was also reported by the Department of Energy, USA. The report can be concluded as follows: in 2012, the indicated price of installed solar panels is \$4.39/W for 5.1 kW residential systems, \$3.43/W for 221 kW commercial rooftop systems, \$2.79/W for 191.5 MW fixed-tilt utility-scale systems, and \$3.37/W for 191.5 MW one-axis-tracking utility-scale systems. Indeed, it was projected that prices will continue to decline to around \$0.74/W in 2013, as well as the inverter prices (see Figure 6).

3.4.1. Capital Investment. In the simulation, the amount of solar panel system investment (including inverters,

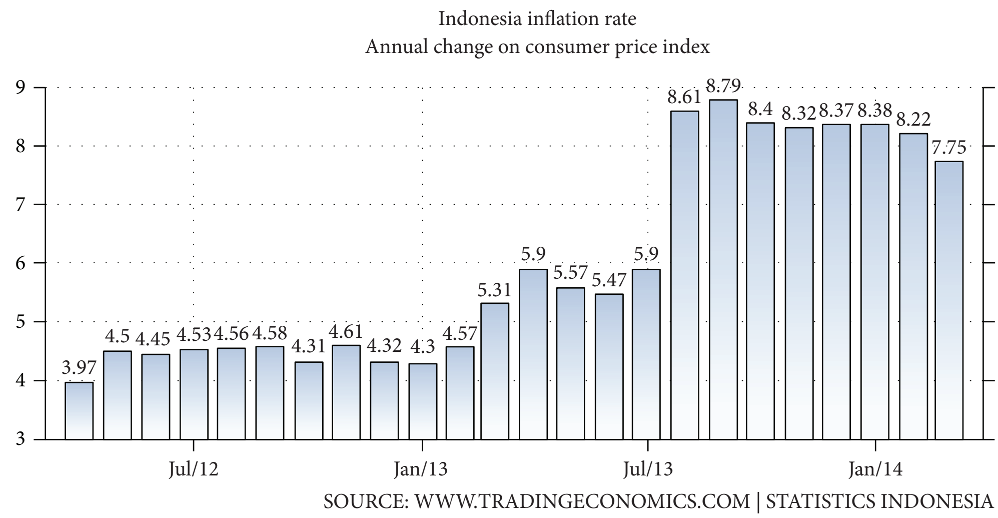

FIGURE 7: Indonesia inflation rate. Source: http://www.tradingeconomics.com.

TABLE 2: History of BI rate in 2011–2014.

Year	Average BI rate
2014 (November)	7.5%
2013	5.75%
2012	5.77%

Source: http://www.bi.go.id.

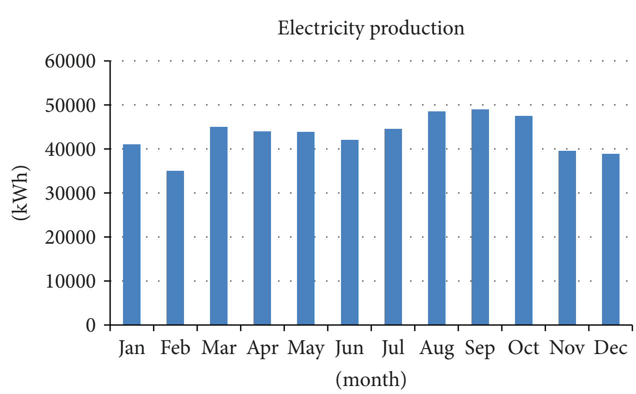

FIGURE 8: Results of simulation of electricity production from PV panels.

structures, and other installation costs) was determined at US $3.00/Watt peak. The watt peak of a solar panel is the maximum amount of power in a predetermined condition which is called "standard test condition (STC)." The STC is a condition in which the solar radiation is 1000 W/m^2, the air mass (AM) is 1.5, and the temperature is 25°C.

3.4.2. Operating and Maintenance Cost. The operation and maintenance costs are calculated in the form of annual fees that also include insurance costs [5]. The annual fee was determined as 1% of the initial investment cost. In general, the cost for maintaining PV systems is quite cheap as compared to the conventional electricity costs.

TABLE 3: Comparison of life cycle cost between the concrete and PV rooftop.

	Concrete roof (IDR)	The total solar panels (1550 panels) (IDR)
Initial cost (IDR)	4,800,000,000	13,400,000,000
Annual energy cost	624,000,000	—
Annual maintenance cost	48,000,000	90,000,000
Nonannual maintenance cost (for 25 years)	2,400,000,000	—
LCC	19,400,000,000	14,100,000,000

3.4.3. Service Life. The calculation for service life in this study was based on the warranty period issued by the manufacturer. Generally, the solar panel warranty ranges from 20 to 25 years. Therefore, this study used 25 years as an input for the service life.

3.4.4. Inflation Rate. The inflation rate in Indonesia can be seen in Figure 7. The average inflation rate in Indonesia was from 3–8% during the four-year period. The rate simulated in this study, therefore, was determined at 7%.

3.4.5. Discount Rate. The calculation of the life cycle cost requires the calculation of the "present value" in order to anticipate the price increases in the service time span (service lifetime). The present value is determined by the "discount rate" number. For this study, the figure was taken from the Bank Indonesia rate (BI rate). Table 2 shows the annual average rate of Bank Indonesia (BI), and the rate used for the simulation is 7.5%.

4. Results and Discussion

4.1. Electricity Production. The results of the EnergyPlus simulation can be analyzed in Figure 8. The total production of electricity from solar cell technology was 519,618.6 kWh per year, and the highest electricity production was in September at 49,278.11 kWh, while the lowest was in February at

Table 4: Comparison of the present value and annual value.

Component	Concrete roof		Solar panel roof	
	Present value (IDR)	Annual value (IDR)	Present value (IDR)	Annual value (IDR)
Initial cost (IDR)	4,800,000,000	566,000,000	13,400,000,000	1,580,000,000
Annual energy cost	13,800,000,000	1,620,000,000	0	0
Annual maintenance cost	364,248,000	42,912,000	683,000,000	80,460,000
Nonannual maintenance cost (for 25 years)	515,868,000	60,648,000	0	0
Total life cycle cost	19,400,000,000	2,290,000,000	14,100,000,000	1,660,000,000

35,426.94 kWh. The result of this simulation is then used as the input data for the energy cost by multiplying with the local electricity price.

4.2. The Life Cycle Cost Comparison of Concrete and PV Rooftop. Table 3 shows that the life cycle cost number can be improved by 27.6% for 25 years or there was a reduction in expenditure of IDR 5,367,072,000 for 25 years.

The reduction of life cycle cost on the solar panel roof was caused by the absence of the annual energy cost and the nonannual maintenance cost. The nonannual maintenance cost of the concrete roof comes from the insulation cost of the concrete roof, such as the recoating work every 10 years in order to protect from the weather effect. The comparison of the present value and “annual value” of each roof can be seen in Table 4.

It can be seen from Table 4 that the present value and annual value had also increased to around IDR 5,367,072,000 and IDR 632,196,000, respectively. Therefore, the saving to investment ratio (SIR) was 1.62. The SIR is the value of comparison between savings and initial investment costs. Based on the results, the solar panel roof was simply “cost-effective” because it had a value above 1. Furthermore, the discounted payback simulation results appeared in the 15th year.

A similar study has been conducted by Nilima et al. [6]. They studied a comparative life cycle cost between an existing building without energy efficient approach and with energy efficient approach. The result showed that a building with energy efficient approach by applying solar panels system as the energy source can reduce the LCC of the existing building effectively. The reduction was around 50% with the average inflation rate as per consumer price index: 7.8%, the average inflation rate as per energy index: 3%, and the average interest rate as per Reserve Bank of India: 8%.

5. Conclusion

This study has simulated a large production of electricity from a roof made of monocrystalline silicone solar panel with an efficiency of 21.6% and the capacity of 240 watt peak. The simulated annual electricity production is around 519,619 kWh. The results have shown that the use of solar panels is more cost-effective since the life cycle cost value was improved at around 27.6%, and the saving to investment ratio was above 1 or 1.62. Furthermore, the investment return value is at year 15 whereas the service lifetime of the solar panel is 25 years.

Conflicts of Interest

The author declares that there are no conflicts of interest regarding the publication of this paper.

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