Analysis of Building Integrated Photovoltaic Application for Apartment Building in Jakarta (Case Study: Pasar Jumat Apartment)

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Diterima: 7 Januari 2022; Direvisi: 12 Juli 2022; Disetujui: 25 Juli 2022

ABSTRACT

In sustainable development concept, energy efficiency and conservation measurements are paramount to reduce the level of building energy consumption. Utilization of such device diminishes the building dependency to the grid which is still dominated by energy from fossil fuels. Implementation of BIPV (Building Integrated Photovoltaic) system is expected to be one of the best possible choices for a tropical country such as Indonesia with abundance of solar radiation. With the existence of BIPV system, it is also expected to reduce the burden of electricity cost for the building management and occupants. This research is considerably new for government building and it also generates a formula to calculate minimum area and the amount of PV panels needed for apartment in Jakarta. Pasar Jumat Apartment is selected to be a subject for this research as the apartment is classified government building which was built and managed by Ministry of Public Work and Housing. Moreover, the apartment has modelled with BIM and already had green building concept. Based on the physical feasibility and financial analysis, BIPV system is found to be more promising and profitable if it is implemented at "Pasar Jumat Apartment" for a long term in the future.

Keywords*: Building, Energy, Integrated, Photovoltaic, Sustainable*

INTRODUCTION

Building sector is one of the biggest contributors for CO^2 emission by its energy consumption. The emission itself is surely responsible for global warming effect. In 2040, the building energy consumption is predicted to reach nearly 80% of global energy consumption. Thus, sustainable development concept is chosen to reduce the level of building energy consumption, as well as application of renewable energy generation device in term of energy efficiency and conservation measurements.

In Indonesia, sustainable development concept is already written on The Ministry of Public Works and Housing's regulation No. 21/PRT/M/2021 about Performance Assessment of Green Building. This law [1] talks about the green building principle, how to assess, as well as the participatory design towards energy efficiency for building. In 2025, efficiency energy is targeted to reach 15-30% for residential building. There is also another regulation for green building called Greenship and has been certified by Green Building Council Indonesia as independent sector who commits to the sustainable development application.

To foster the mission of efficiency energy target, Building Integrated Photovoltaics (BIPV) system implementation is expected to be one of the best possible choices for a tropical country such as Indonesia with abundance of solar radiation. It can be used to accommodate the electrical consumption in operating shared facilities of apartment buildings, which are installation system of public area lighting, services, landscape, public announcement system, and ground water tank pump. With the existence of BIPV system, it is also expected to reduce the burden of electricity cost for the building management and occupants. Hence, this research was conducted to observe the performance of BIPV system to meet the energy load for public space if installed in apartment building, especially in Pasar Jumat Apartment. Several options of PV panel installation are measured to figure out the most optimal PP (Payback Period) and BCR (Benefit Cost Ratio).

Pasar Jumat Apartment (Figure 1) is a fully furnished apartment that is built for Civil Servants in The Ministry of Public Works and Housing Republic of Indonesia and finished in 2020. The site is located in South Jakarta, Indonesia, which has 12.5 hours of daily sunshine duration and hot humid climate with air temperature between 28°C - 36°C. The building has U-shaped design with double loaded corridor and was planned to accommodate 1,200 people with 18 stories which has 410 housing units consist of 360 units type 36 m^2 and 50 units type 72 m^2.

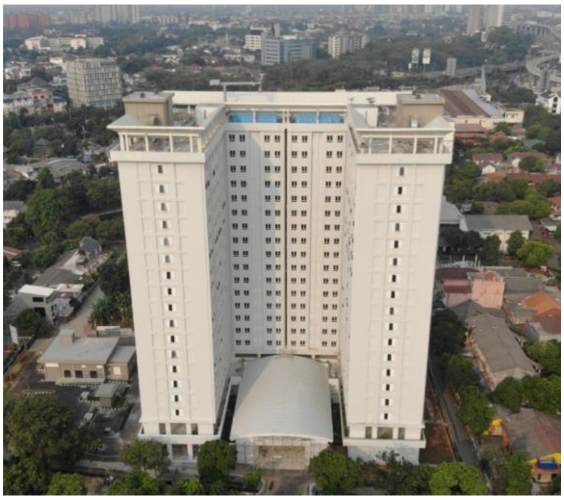


Figure 1 Pasar Jumat Apartment

Building orientation is facing the East that will make the building façade broader in East and West sides of the building. Figure 2 shows the simulation of the Sun position towards the building by using Autodesk Revit software.

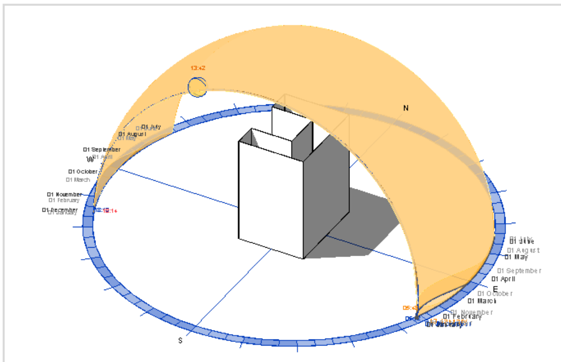
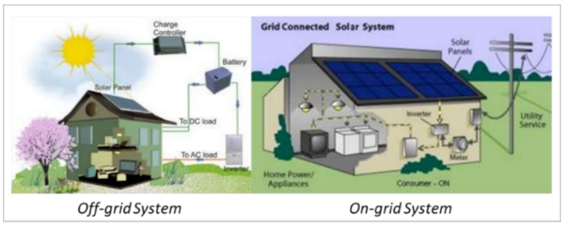


Figure 2 Simulation of the Sun Position in Pasar Jumat Apartment

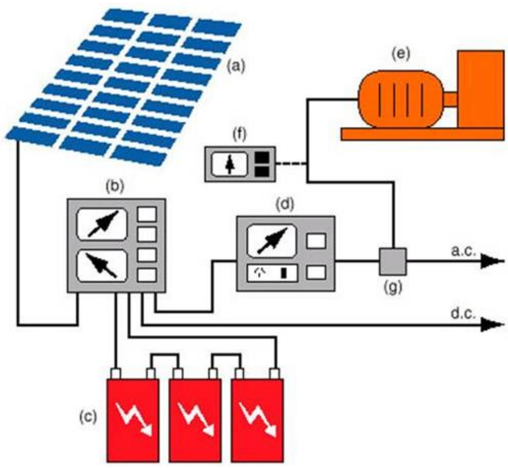
LITERATURE STUDY

BIPV can be defined as a photovoltaic generating component which forms an integral and essential part of permanent building structure without which a non-BIPV building material or component would be required to replace it. BIPV system is able to stand alone (off-grid system) or connected to the electrical network (on-grid system). Off-grid system uses the Sun as the only main electrical source by using PV, meanwhile on-grid system is connected to the electrical network by maximizing the energy usage from PV [2]. The system configuration of on-grid and off-grid system shown in Figure 3. In this research, BIPV system with on-grid system was used to make sure the power was always filled. The diagram system of PV shown in Figure 3.

Feasibility study parameter for this research is financial aspect (investment and the number of efficiency energy) and technical aspect (PV lifetime, component changing time, etc). In general, there are some obstacles in the PV application, they are: modal cost for solar is expensive; massive needed for battery channel; high-cost battery maintenance that needed to be replaced once in the duration of 3-5 year [3]. BIPV system has been used in some places, such as CYC Building, Hong Kong University [4] and apartment in North Cyprus [5]. Furthermore, the advantages of using BIPV [6] are: increase building function, quality, and reliability of electrical devices.



(a)



a. PV modul
b. Controller
c. Battery
d. Power conversion tool
e. Generator set
f. Supporting tools, cable network, and electric circuit.

(b)

Figure 3 (a) BIPV System Configuration of Off and On Grid and (b) PV System Diagram

METHODOLOGY

In this paper, the analysis was conducted using quantitative method by using equations which are stated by Duffie and Beckman [7], and was executed with Microsoft Excel. The aspects which were involved in the calculation, i.e. energy consumption, sun radiation, energy output from solar panel, investment and maintenance cost, as well its efficiency energy percentage. Furthermore, comparison analysis method was used to analyze the calculation output from quantitative method towards its comparison energy calculation. In the analysis process, energy efficiency and feasibility study (Benefit Cost Ratio and Payback Period) of BIPV were analyzed. Moreover, recent studies and SWOT analysis were conducted to identify the benefits, problems, and potential of BIPV system which were installed on the apartment building. The research methodology can be seen in Figure 4.

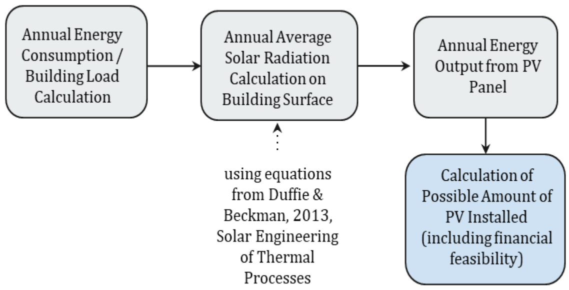


Figure 4 Research Methodology

CALCULATION

Load Calculation

The building load or energy consumption determined in this study was for shared facilities, including installation system of public area lighting, services, landscape, public announcement (PA) system, and ground water tank pump. The lighting system consists of lobby hall lighting, corridor, public toilet, guest and service lift lobby, function hall, pre-function hall, parking area, and emergency stairs. The PA system consists of speakers on ceiling, walls, and columns. The building load was calculated based on energy consumed every hour which is shown in Figure 5. Hourly load distribution was determined based on activities assumed in Pasar Jumat Apartment. In general, the energy consumed tended to be stable after midnight until afternoon with a bit of fluctuation between 5 am – 9 am. Meanwhile, the load increased significantly after 5 pm. Figure 5 also shows that the apartment had a baseline of 9.25 kWh consumed at 1 am – 4 am and the peak load happened at 6 pm, which was 20,8 kWh.

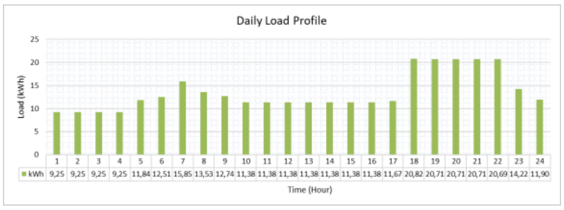


Figure 5 Building Load Diagram of Shared Facilities in Pasar Jumat Apartment

Solar Radiation Calculation

Solar radiation on the building surfaces, which are facades and roof, was also calculated to understand the amount of potential energy that can be harnessed from the sun. Energy from solar radiation was calculated on hourly basis for a year (assumed that the radiation within a month will be the same for each day). The measurement unit used was Wh/m^2 or kWh/m^2. To determine the amount of solar radiation, the value of some variables should be set up, such as location coordinate, azimuth angle, declination angle, sunset hour angle, albedo, extra-terrestrial solar radiation, and clear sky index. Most data were gathered from the official website of NASA Atmospheric Science Data Centre. The result of daily solar radiation calculation on every surface is shown in Figure 6. Based on the calculation, the result showed that the highest value of average annual solar radiation was found on the horizontal (roof) surface, reaches 6.29 $kWh/m^2/day$. The east and west side got more than half the radiation on the horizontal surface, which were 3.8 $kWh/m^2/day$ and 3.75 $kWh/m^2/day$.

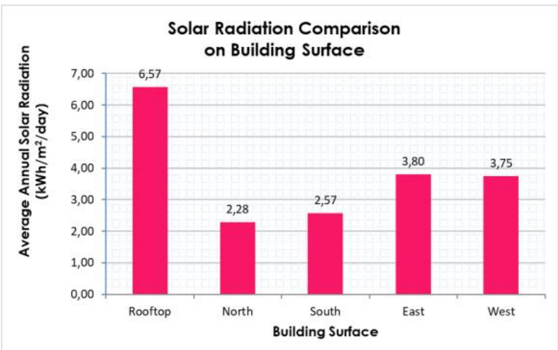


Figure 6 Comparison of The Average of Annual Solar Radiation on The Building Surface

Energy Generated From PV

In term of its high efficiency and reliability, monocrystalline PV was selected in this study. Panasonic VBHN320KA01, a monocrystalline PV panel, was used in this study as a sample for calculation. The product has power output of 320 W with 19.1% of module efficiency and area 1.67 m^2. There were some aspects which affected the calculation, i.e. solar radiation on the building surface, PV specification, ambient temperature, PV array and inverter efficiency, and the number of PV installed. In this case, PV panels were installed covering the solid surface of the building. Transmission line loss of the system did not take into account in this exercise. The calculation result of the amount of possible PV installation is shown in Table 1. Based on the mathematical equation, energy output from PV for each side of the building is illustrated in Figure 7. Figure 7 also shows the imported energy required and the possible exported energy as surplus from PV system which uses 1,157 units PV panel. The PV system produces energy according to sunshine duration on the location, estimated from 6 am to 6 pm or around 12 hours daily. The system will be grid connected, so that the electricity supply will be uninterrupted, especially when the sunshine is insufficient to generate electricity. Otherwise, any surplus of electricity can be sold to the grid.

Table 1 Sample Calculation of Possible Amount of PV Installation in Pasar Jumat Apartment

Building Surface	Area of Building Surface	Possible Amount of PV Installed
Rooftop	716.59 m^2	427 unit
North Façade	241.46 m^2	144 unit
South Façade	241.46 m^2	144 unit
East Façade	216.26 m^2	129 unit
West Façade	524.29 m^2	313 unit
Total	1,940.46 m^2	1,157 unit

Source: author, 2021

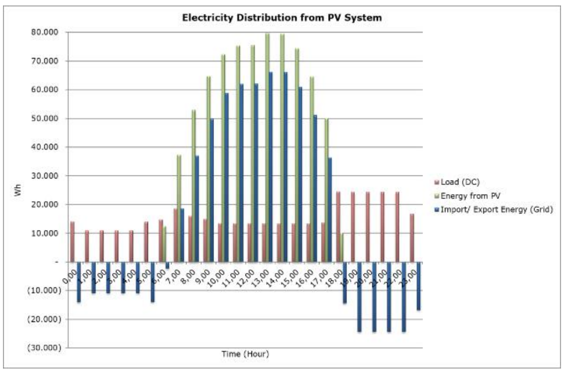


Figure 7. Energy Diagram Distribution from PV System

DISCUSSION

Financial Feasibility

Financial feasibility of BIPV implementation can be estimated by analysing Benefit Cost Ratio (BCR) and Payback Period (PP). BCR is calculated by dividing annual profit including Net Present Value (NPV) by initial cost. The value of BCR should be more than 1 to be classified as a beneficial project. On contrary, the value below 1 means the investment is still greater than the benefit. Meanwhile, PP is calculated by dividing initial investment by annual profit. BCR and PP calculations can be used only as a mainframe to see potential of the project, instead of the exact calculation, because variables other than those being calculated are not taken into account in this study. Assuming inflation rate in Indonesia is 5.49% per annum, electricity price is USD 0.08/kWh, and electricity selling price to the grid is USD 0.11/kWh [8] and [9], therefore the result of BCR and PP calculation of BIPV implementation in Pasar Jumat Apartment is elaborated in Table 2.

Table 2 Calculation of PP and BCR of PV Installation in Pasar Jumat Apartment

Description	Nominal
Unit Price of PV Panel	USD 350
Initial Cost (1,157 units of PV Panel)	USD 404,950
Electricity Price without BIPV System	USD 9,783 /annum
Electricity Price with BIPV System	USD 6,097 /annum
Saving Potential (a)	USD 3,686 /annum
Export Grid (b)	USD 22,568 /annum
Total Saving (a+b)	USD 26,568 /annum
Payback Period (PP)	15 years
Benefit Cost Ratio (BCR)	0.83

Source: author, 2021

To get more optimum result of PP and BCR, the composition of PV panels installed can be adjusted based on the amount of solar radiation on building surface. The composition of PV panels on each building surface is shown in Table 3.

Table 3 Calculation of PP and BCR Based on PV Panels Composition

Option (Installation Amount)	Total Amount of PV Installed	Initial Cost (USD)	Potential Annual Saving (USD)	Payback Period (PP)	Benefit Cost Ratio (BCR)
Opt. A (100% installed on each facade)	1,157 units	404,95	26,253	15 years	0.83
Opt. B (100% installed on East and West Façade)	869 units	304,15	22,377	14 years	0.95
Opt. C (100% installed on North and South Façade)	715 units	250,25	17,226	15 years	0.88
Opt. D (50% installed on each façade)	792 units	277,20	19,801	14 years	0.92

Source: author, 2021

Based on the results shown in Table 3, Option B has 14 years of PP and 0.95 of BCR which makes the option more favourable compared to the others. Nevertheless, in general, PP should be achieved between 6 to 8 years on average. Although Option B has the highest BCR, it is still below 1 that shows the initial investment is higher than its return. The initial cost of BIPV system implementation in South East Asia is considered higher than in Europe and North America that can reach three times than average [10]. This may be caused by high labour costs and imported photovoltaic materials. Using NPV and Discounted Payback Period (DPP), a study in Bahrain shows that DPP of BIPV system more than the life cycle of the system due to its high initial cost [11]. Thus, investment on BIPV is financially not interesting for current situation in Pasar Jumat Apartment.

Physical Feasibility

The available technology nowadays uses monocrystalline silicone that provides higher efficiency, lifetime, and more environmentally friendly as PV panel material. Yet the local industry in Indonesia is not able to produce PV panels independently that makes the investment cost rising. Nevertheless, Indonesian government is showing some supports by authorising Feed in Tariff (FiT) policy or incentive for those who want to have BIPV system and preparing the local PV panel industry for the future. Thus, it is physically capable to implement BIPV system and will be more beneficial in the future as a long-term investment. In upcoming years, BIPV may have 25%-50% of cost reduction, in which the value will be sufficient to broaden BIPV market [12].

CONCLUSION

The combination of design, delivery system, and PV technologies selection play significant role in the efficiency and effectiveness of BIPV system. 869 units of PV panels are needed to be installed to get optimum value of BCR and PP. Based on the calculation of solar radiation potential in Pasar Jumat Apartment location, rooftop area (horizontal surface) had the highest solar radiation reaching 6.57 kWh/m^2/day which made the area exceptionally suitable for PV panels installation. Besides rooftop area, East and West façades also had higher solar radiation compared to the North and South, although the panels' temperature will rise above its optimum level due to the sun's heat on East and West side. This will determine the proportion of PV panels installation, which are 427 units on rooftop, 129 units on East façade, and 313 units on West façade that will produce 748,545 Wh of energy in a day. The amount of energy might cover building load on public area lighting system, services, public announcement system, and ground water tank pump. However, the Benefit Cost Ratio (BCR) calculation showed that the profit from BIPV system still could not cover the investment cost, as well as the Payback Period (PP) that reached 14 years had not favourable yet for the system to be implemented at the moment. Despite its BCR and PP, Indonesian government encourages every party to use BIPV system by issuing FiT policy, giving incentives, and strengthen local industry to diminish import on PV panels.

RECOMMENDATION FOR DESIGN CRITERIA

Geographical Criteria

Indonesia is gifted with solar energy potential as the country has 12 hours of average sunshine duration a day. This potential can be disrupted by weather condition and dust that might affect PV panel efficiency [13]. Accumulation of dust will reduce the power output by 12.7% per month, whereas cloudy weather may decrease the efficiency by 10% per month [14]. Thus, BIPV system is suitable, yet routine maintenance is required to maintain its efficiency and power output at good condition.

Minimum Surface Area for PV Installation

Total energy consumption in Pasar Jumat Apartment was about 381.8 kWh/day. Building load, which is total energy consumption, affects the minimum numbers of PV panel and minimum surface area required for installation. The surface area for each façade can be determined by dividing the total building load and output energy from PV (per m^2). In Pasar Jumat Apartment, the output energy derived from PV per m^2 for each façade is shown in Table 4.

Table 4 Output Energy from PV (per m^2)

Building Surface	Energy from PV System (kWh/day)	Surface Area Required for PV Panel (m^2)	Output Energy from PV System per m^2 (kWh/m^2/day)
Rooftop	403.51	716.59	0.56
North Façade	47.71	241.46	0.20
South Façade	53.45	241.46	0.22
East Façade	71.92	216.26	0.33
West Façade	171.96	524.29	0.33

Source: author, 2021

Based on the information on the table above, minimum surface area required for PV installation can be calculated to cover energy consumption in an apartment building in Jakarta, Indonesia. Calculating the surface area can use this following formula.

$$Surface\ area\ required\ for\ PV\ panel = \frac{\sum Building\ load\ (kWh/day)}{Output\ energy\ per\ m^2 (kWh/day/m^2)} \quad (1)$$

As an example, the surface area required in an apartment building with 84.8 kWh/day of energy consumption can be determined and the result is presented in Table 5. Table 5 shows the minimum surface area needed if PV panels are installed on one side of the building. Further study is required to obtain optimum composition of panel installation.

Table 5 Surface Area Required for PV Panel

Building Surface	Output Energy from PV System per m2 (kWh/m^2/day)	Surface Area Required for PV Panel (m^2)	Number of PV Panel Installed*
Rooftop	0.56	150.60	91
North Façade	0.20	429.21	258
South Façade	0.22	383.08	230
East Façade	0.33	254.99	153
West Façade	0.33	258.55	155

* Area of PV Panel: 1,67 cm2/ panel

Source: author, 2021

ACKNOWLEDGEMENTS

All praise to God, the Almighty, on whom the authors seek guidance to live and finish this research. The authors would like to express gratitude to Director, Head of Sub Directorate, and our colleagues in the Directorate of Vertical Housing, Directorate General of Housing Provision, Ministry of Public Works and Housing, for all the supports and supervision during this research.

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