Application of Building Integrated Photovoltaic in Hot Humid Climate. Case Study: Office Building in Indonesia

N A Ardiani1,2, Suhendri1,2, M D Koerniawan1,2 and D Y N Naimah2

1 Department of Architecture, Institut Teknologi Bandung, Bandung, Indonesia, 40132
2 Centre for Development of Sustainable Region (CDSR), Yogyakarta, Indonesia, 55281

*Corresponding email: nissaardiani@gmail.com

Abstract. This study investigated application of photovoltaic (PV) panels for office building. Bandung, Indonesia is chosen as case study due to its hot and humid climate. To conduct this study, first, site selection was evaluated, followed by load evaluation using standard requirement for energy-efficient office building. Then, design and size of the system was defined. Feasibility of this study was evaluated from technical and economic indicators, i.e. energy delivered, energy export and import to the grid, yearly savings, and payback period. Simulation of this study was performed with various scenarios on the design electricity load. This study shows that solar PV panels are feasible to be installed in flat roofs and western façade. With 365 m² of solar panel in total, it can generate 66 MWh electricity per year. If PV provide electricity for lighting inside the building, the payback period is 12 years. This payback period become faster, i.e. 6.24 years, if all the electricity is sold to the grid.

1. Introduction

Renewable energy systems in buildings are now more widely used because more people aware about decreasing fossil energy and greenhouse gas emission. They try to find and explore how to implement sustainable building concept into buildings. The active system of renewable energy has been studied and practically applied in the buildings with additional benefit to reduce the electrical bills from the grid. For building application, sustainable energy systems become slightly affordable to be applied in the small to large scale building.

Building Integrated Photovoltaics (BIPV) technology and its application in the façade construction enhance aesthetic of the building, improve economic, and technical issues [1]. In the past decade, BIPV as a renewable power generation source has been contribute partially in meeting electrical and thermal loads of the building [2].

BIPV application could give a noticeably different result depends on its location. Different selected location implies in deviating climate, built environment, structure of electricity industry, market stimulation mechanisms, government policies, the offering of local product, end-user demand, current industrial performances and the forms of tariff calculation for grid-connected [3]. Norton et. al. also stated that grid-connected BIPV is the simplest system consist of PV array and inverter that connect directly to the conventional electricity network or source so that batteries are not mandatory. Therefore, performance of the system depends on local climate, PV efficiency, array’s orientation and inclination, energy load characteristics and the inverter [3]. Luthander et. al. reviewed papers about PV self-consumption and examine the alternatives to enhance the produced electricity load that can be
consumed by the building directly, which are battery storage and demand-side management (DSM) [4].

In the tropical regions where solar radiation and temperature are relatively high, PV has a negative impact on the building’s thermal performance. Previous studies showed that PV installation might lead to high indoor temperature due to its non-responsive climate material (low thermal mass) [5]. The utilization of BIPV has not been widely applied in developing countries such as Indonesia. People are still thinking that installing PV system is expensive so that subsidized electricity are cheaper. However, PV as renewable energy sources would be beneficial to meet the electricity needs without relying on the electricity supply from the grid. Nevertheless, technical issues with its application that might occur in the operation of the buildings must be handled carefully.

This study aims to examine the feasibility of solar PV application and its performance in the specific location by considering weather data e.g. solar radiation and ambient temperature. The design would incorporate standard requirements of office buildings while bring comfort to the occupants.

2. Methodology and Strategies
In this paper, renewable energy systems i.e. a small-scale building integrated photovoltaic (BIPV) system were calculated and simulated to examine the feasibility of it for an office building, in Bandung, Indonesia. The BIPV would be studied in the ongoing real project of Institut Teknologi Bandung’s (ITB) new office buildings named ITB Innovation Park Ganeča (IIP Ganeča). It consists of the 4-story building with floor area of 1,540 m² and a flat rooftop (See figure 1). As can be seen in figure 2, this office building is located on Ganeča Street, just across the ITB Ganeča campus. However, the longest façades of the building are facing East and West due to limitation of available site location.

![Figure 1. The application of the BIPV in the ITB Innovation Park Ganeča Building](image)

This study conducted in four steps, i.e. site analysis, load evaluation, calculation of size and design of the BIPV, and the last is energy and economic analysis. Detail of all the four steps are described below.

2.1. Site analysis
Several simulations were run using Bandung, Indonesia as location of the building. Geographically, Bandung is located in 6.91° South and 107.60° East. Bandung is categorized as a hot and humid climate. The average amount of solar radiation (HT) in Bandung, Indonesia is 483.3 Wh/m². This measurement starts from 6 am until 6 pm in the horizontal plane 0°. Because its location near the equator line, the average of solar radiation is quite high, and it is possible to utilize photovoltaic panel to produce electricity. The ambient temperature of this location was recorded with a minimum of 17°C, maximum of 29.2°C, and average 23.3°C according to climate-data.org [6].
2.2. Load Evaluation
In load evaluation, number of occupants and standard requirements in an office building in Bandung were considered. According to Energy Use Intensity (EUI) by ASEAN-USAID study in 1987, it is proposed that the EUI for an office building in Indonesia is 240 kWh/m²/year [7]. However, Minister of Energy and Mineral Resources regulations in 2012 stated that an efficient office building using air conditioning should consume 8.5-14 kWh/m²/month or about 102-168 kWh/m²/year [8]. The total daily load was then dispersed into 24 hours depending on the electricity use and scheduling in the office building. Energy load for lighting is 15% of the total energy consumption of the building [9].

2.3. Determine the size and design of PV systems
For the simulations, the PV type used is the 250 WP Greentek Polycrystalline with Inverter On-Grid ICASolar 20 kW. The cost of the package consists of 88 PV Panels 250 WP and Inverter 20kW was IDR 522,500.000 or USD 35,761.21 and cost of the package consists of 48 PV Panels 250 WP and Inverter 10kW was IDR 285,000.000 or USD 19,734.79 [10].

2.4. Analyze the energy produced by the systems and the simple payback period of PV application

3. Calculation and result
The PV system used in the building are using these formulae:

- Energy delivered = \( \eta_a \times (A \text{ module} \times \text{PV array}) \times \text{Solar radiation} \) (1)
- Energy grid (import/export) = (Energy delivered \( \times \eta_{inv} \)) – energy load DC (2)
- Savings per year = (Energy load DC \( \times \) electricity tariff/kwh \( \times \) 365 days \( \times \) 0.85) + (Energy export to grid \( \times \) feed-in tariff/kwh \( \times \) 365 days \( \times \) 0.85) (3)
- Simple payback period = \( \frac{\text{initial cost (Ic)}}{\text{first year savings (Ic)} \times \Delta Ec} \) (4)

In this calculation, if the Energy grid is in a positive number, it means that the PV is exporting electricity to the grid. The total exported energy was then multiplied by fit-in tariff/kWh. In contrast, if the Energy grid is in a negative number, it means that the PV is importing electricity from the grid. The total imported energy was then multiplied by tariff/kWh. In total, there are 224 PV arrays which is applied in to the roof and the western façade.

If the PV covered the whole building with energy load of 240 kWh/m²/year, it could deliver a total energy of 65,957 kWh/year and still need to import 368,867 kWh from the grid. After calculating the savings per year, the payback period of investing 224 PV panels is 15 years.

If the PV only covered the energy load for lighting which is only 15% from total building energy load (36 kWh/m²/year), it could deliver the same total energy of 65,957 kWh/year and it will export of 733 kWh/year to the grid. The payback period would reduce to 12 years.
A calculation was performed to see the difference if the total energy load reduces to 150 kWh/m²/year and if the PV arrays reduced to 176 panels. The initial cost for investing 224 PV panels was IDR 1,330,000,000 or USD 91,997.43 while for 176 PV panels was IDR 1,045,000,000 or USD 72,283.69. The result of the calculation can be seen in Table 1.

Table 1. Energy delivered in one day and yearly savings

| Energy load baseline kWh/m²/year | Electrical Energy Load DC / year kWh | Total PV Panels Pcs | Energy delivered /year kWh | Import/Export kWh | Savings /year IDR | Payback Period years |
|---------------------------------|-----------------------------------|---------------------|---------------------------|------------------|------------------|---------------------|
| 240 (total)                     | 434,824                           | 176                 | 58,075                    | -376,749         | 78,981,898       | 14.00               |
| 36 (lighting)                   | 65,224                            | 176                 | 58,075                    | -7,149           | 93,800,121       | 12.00               |
| 150 (total)                     | 271,765                           | 176                 | 58,075                    | -213,690         | 78,981,898       | 14.00               |
| 22.5 (lighting)                 | 40,765                            | 176                 | 58,075                    | 17,310           | 125,035,309      | 9.00                |

After having the result of previous calculation, the payback period of investing renewable energy application in IIP Ganeca could be faster if the energy load that covered by PV panels are lower. In Table 1, reducing energy load result in higher exported energy to the grid which also followed by the increment of yearly savings. However, when the PV covered 240 kWh/m²/year and changed into 150 kWh/m²/year to meet the standard of an efficient office building, the amount of yearly savings does not change. The calculation with the same method was then continued to unveil how many loads covered by PV that could increase yearly savings. It is revealed that when the PV only covered less than 80 kWh/m²/year, the yearly savings increased, and the payback period decreased. When the load covered is 0 kWh/m²/year, which means all the energy delivered by PV was exported to the grid, then the income from fit-in tariff is the maximum with payback period reduce to 6.24 years. The result can be seen in Table 2 below.

Table 2. Simulation of load covered by PV to calculate yearly savings and payback period

| Load covered by PV kWh/m²/year | Savings and Income from PV IDR | Payback Period years |
|--------------------------------|--------------------------------|---------------------|
| 240                            | Rp 89,701,156.21                | 14.83               |
| 220                            | Rp 89,701,156.21                | 14.83               |
| 200                            | Rp 89,701,156.21                | 14.83               |
| 180                            | Rp 89,701,156.21                | 14.83               |
| 160                            | Rp 89,701,156.21                | 14.83               |
| 140                            | Rp 89,701,156.21                | 14.83               |
| 120                            | Rp 89,701,156.21                | 14.83               |
| 100                            | Rp 89,701,156.21                | 14.83               |
| 80                             | Rp 89,701,156.21                | 14.83               |
| 60                             | Rp 90,368,889.94                | 14.72               |
| 40                             | Rp 104,620,440.6                | 12.71               |
| 20                             | Rp 155,701,061.4                | 8.54                |
| 0                              | Rp 213,040,246                  | 6.24                |
4. Conclusion
To sum up, the application of renewable energy resources such as PV panels in an office building in Bandung, Indonesia could reduce electricity bills. 224 modules of PV panels applied in the flat roof and western façade of IIP Ganeca with a total area of 365 m². The study shows that the system could generate electricity almost 66 MWh per year. The PV panels should be placed in 00 tilted roofs and the 90o tilted western facade where the solar radiation higher than the other side to obtain maximum result. This study also revealed that the lower energy load covered by the PV, the yearly savings will be increased and lessen the payback period. The fastest payback period is gained when electricity from PV panels are sold to the grid.

However, it is important to maintain the PV panel’s temperature remains stable to avoid overheating which could resulting inefficiency. Surely, the advance calculation to lessen the payback period which considering the summation such as calculation of value per building component, discount rate, incentives, etc. The increased value that could be used by building owner because the building has fulfilled the Green Building certification, will also be a benefit for marketing. From this calculation and simulation, we could also convince that if Indonesian government would give more incentives for every renewable energy system applied, the impact would be greater than business as usual and the energy could be utilized for the other needs such as public services.

5. References
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Acknowledgments
Authors wishing to acknowledge assistance or encouragement from our colleagues in Department of Architecture, Institut Teknologi Bandung. We gratefully acknowledge the funding from USAID through the SHERA program - Centre for Development of Sustainable Region (CDSR).