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Evaluation of BIPV performance based on the Greenhouse Standard: Towards Net Zero School Building

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Abstract: *Buildings at various stages of life pose a challenge to energy production. Energy can be generated from a variety of sources, both renewable and nonrenewable. Switching from nonrenewable to renewable energy sources is one of many strategies that can be used to achieve net-zero buildings. In Indonesia, this strategy is very feasible due to its abundant renewable energy resources, particularly solar energy. This research presents a school building as the proposed case. The school, SCK Citra Garden, is chosen as the pilot project due to its access to solar radiation and its minimum shading conditions. Using Helioscope software, BIPV modelling was simulated on its roof, and the electrical energy output from BIPV was calculated. The substitution percentages of BIPV energy output for conventional electrical energy consumed by the building were then measured. This percentage was compared to the National Energy Mix target and Greenhouse Gas Standard to assess its performance towards net-zero school buildings. The result shows that BIPV has a good performance. Even though the substitution percentage is still below the national energy mix target, it exceeds the greenhouse gas standard target for on-site renewable energy tools.*
Keywords: BIPV, energy mix, Greenship, net-zero buildings, on-site renewable energy

Abstrak : Bangunan di berbagai tahap kehidupan menimbulkan tantangan bagi produksi energi. Energi dapat dihasilkan dari berbagai sumber, baik yang terbarukan maupun yang tidak terbarukan. Beralih dari sumber energi tak terbarukan ke sumber energi terbarukan adalah salah satu dari banyak strategi yang dapat digunakan untuk mencapai bangunan net-zero. Di Indonesia, strategi ini sangat memungkinkan karena sumber daya energi terbarukan yang melimpah, khususnya energi surya. Penelitian ini menghadirkan gedung sekolah sebagai kasus yang diusulkan. Sekolah tersebut, SCK Citra Garden, dipilih sebagai proyek percontohan karena aksesnya terhadap radiasi matahari dan kondisi naungannya yang minim. Menggunakan perangkat lunak Helioscope, pemodelan BIPV disimulasikan di atapnya, dan energi listrik yang dihasilkan dari BIPV dihitung. Persentase substitusi output energi BIPV untuk energi listrik konvensional yang dikonsumsi gedung kemudian diukur. Persentase ini dibandingkan dengan target Bauran Energi Nasional dan Standar Gas Rumah Kaca untuk menilai kinerjanya terhadap bangunan sekolah net-zero. Hasilnya menunjukkan bahwa BIPV memiliki kinerja yang baik. Meskipun persentase substitusi masih di bawah target bauran energi nasional, namun sebenarnya melebihi target standar gas rumah kaca untuk alat energi terbarukan on-site..

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Keywords: BIPV, bauran energi, Greenship, bangunan tanpa energi, energi terbarukan di tempat

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Introduction

Buildings contribute to one-third of world energy consumption (Srinivasan et al., 2011, 2012; Yi et al., 2017) and are still associated as a huge consumer of energy (Pitts, 2004). A huge amount of energy was consumed by a building during its life stages: the construction stage, the operational stage, the renovation and the deconstruction stage. Awareness is raised since the source of the energy mostly comes from fossil fuels, which gives a negative impact on the environment. To reduce the impact, two main strategies can be adopted. Reducing energy consumption and switching to renewable energy resources (S Susan & Wardhani, 2020a, 2020b; Susan Susan et al., 2021). To reduce energy consumption, buildings can either optimize the use of passive design strategies or use energy-efficiency equipment for their active system. Energy-saving-based systems and smart control solutions can be one of many strategies applied in this case (Lai et al., 2020).

To switch to renewable energy, buildings in Indonesia have so many available resources. In Indonesia, as issued by Sekretariat Jenderal Dewan Energi Nasional, there is abundant renewable energy resource (NASIONAL, 2019). It consists of hydropower, geothermal, solar energy, wind energy, ocean energy, and bioenergy. From those resources, solar energy takes a notable amount and the availability reaches 207.8 GWp. Two technology options can be selected to convert renewable energy into electrical energy. They are technology in/on the building or technology on the ground attached to the building, and technology that is placed outside the building and the building owner just purchases the electrical energy produced from the renewable resource (Marszal et al., 2012). Related to the first option of technology, the most potential microgeneration technology to utilize solar energy is photovoltaic (PV). PV becomes very popular since it can be used as an on-site renewable energy tool. To optimize the utilization of PV, the electric power from PV is connected to the PLN electricity network, creating a system called a hybrid connected to a grid system (Sinaga et al., 2019)

The work of PV is influenced by many factors such as temperature, shading coefficient, PV efficiency, solar radiation received, tilt and orientation angle. The electrical energy generated will be optimum if PV has high efficiency, works at 25°C, receive 1000 W/m2 solar radiation, works in minimum shading-coefficient, and is set in optimum tilt and orientation angle (equal to geographical latitude, facing toward the equator). One PV installation system called BIPV (Building Integrated Photovoltaic) gives more advantages such as reducing cost. The use of PV panels as building envelopes will

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substitute the need for conventional building materials. The integrated configuration BIPV based on optimal PV orientation will affect the amount of radiation received, and finally affect the electricity output (Susan Susan, 2017)

Green Building Council Indonesia (GBCI) put on-site renewable energy as one of its criteria in the Energy Efficiency and Conservation Rating Tool. GBCI assess the achievement of on-site renewable energy through the percentages of maximum power demand or numbers of electrical energy that can be generated by renewable energy. 1 credit for 0.25% or 2kWp, 2 credits for 0.5% or 5kWp, 3 credits for 1.0% or 10kWp, 4 credits for 1.5% or 20kWp, and 5 credits for 2.0% or 40kWp (Council, 2020). Related to renewable energy issues, the government has also issued a regulation to encourage the use of this low-emission energy generator. Government Regulation No. 79 of 2014 set the National Energy Policy in Indonesia. In this policy, the government set 23% of the renewable energy mix by 2025 (see figure 1). Another parameter for energy performance is the energy consumption index. For example, the energy performance index for offices is 240 kWh/m2 per year, and for apartments is 300 kWh/m2 per year.

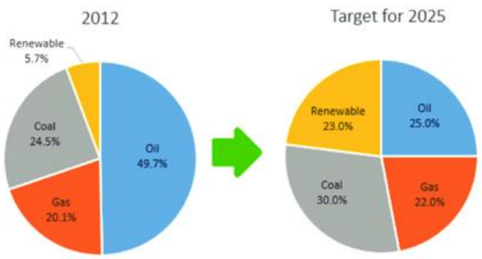

Figure 1. Government National Energy Mix Program (RKS-IPB, n.d.)

Ciputra, as one of the biggest stakeholders in the property industry in Indonesia, is eager to contribute to the government's national energy mix program. Under Yayasan Ciputra Pendidikan, the School of SCK Citra Garden (see Figure 2), which is located in Citra Garden City, West Jakarta, was set up as a pilot project for this program. This school was chosen by Yayasan Ciputra Pendidikan as the pilot project for several reasons. The geographical location of the building at 6° 12' S latitude and 106° 48' East longitude indicates its access to abundant solar irradiance. Additionally, the building receives minimum shading from its surroundings, giving it more advantages in accessing solar irradiance. This paper will analyse BIPV performance on SCK Citra Garden, based on the Greenhouse Standard.

Figure 2. School of Citra Kasih (SCK) Citra Garden, Jakarta.

Methods

The research process begins with the selection of a location. The parameters used to select the site are accessible to solar irradiance and minimum environment shading conditions (Ubisse & Sebitosi, 2009). Once the site is selected, observation is done to determine the building's energy consumption and surface availability. For PV selection, the concern is put on PV internal factors such

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as efficiency, silicon types, watt-peak value, and dimensions (Susan Susan, 2017). The site selection and PV selection will determine the number of PV systems that can be installed on the building (see the site plan in Figure 4). After PV numbers are predicted, the power output is calculated. The power output is calculated based on the multiplication of PV numbers, PV Watt-peak, and loss factor. Meanwhile, the loss factor comes from many sources, such as shading, reflection, soiling, irradiance, etc. The number of BIPV power outputs is then compared to the building's energy needs. The result is measured in percentages and then compared to the Greenhouse standard. The research steps. Research Steps are presented in Figure 3

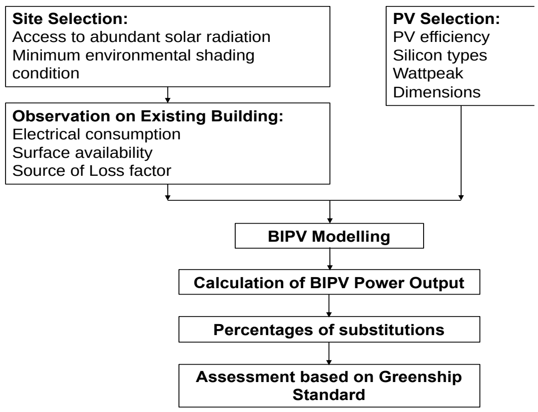
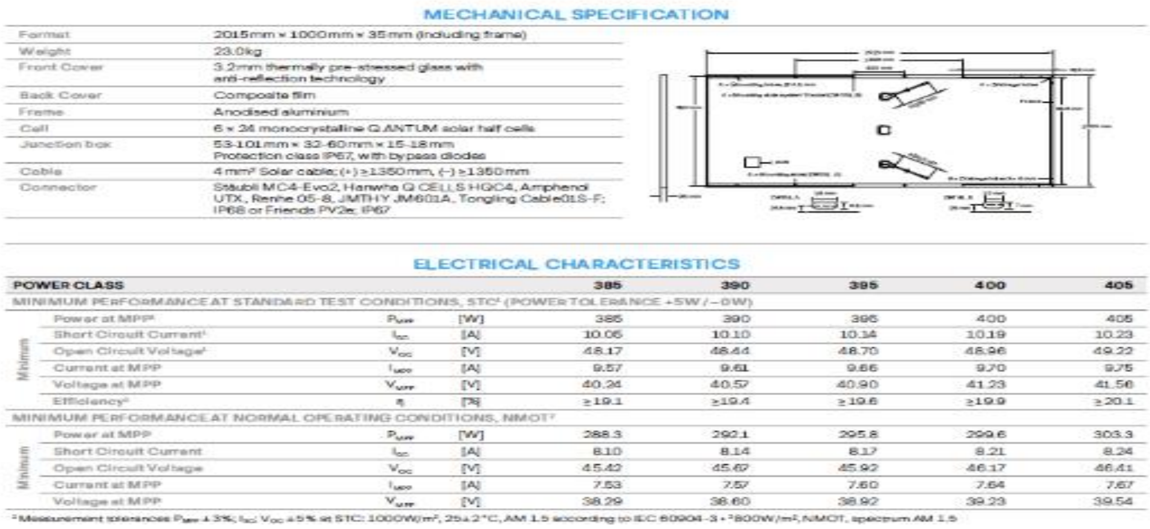


Figure 3. Research Steps

Results and Discussions

The BIPV capacity is determined by school management based on the building's electrical power. The building's electrical power is 197,000 watts. Regarding the initial cost and the availability of the integrated space, the school management is planning a 13–15% substitution of conventional electrical energy. According to this plan, the BIPV capacity required is between 25,610 and 29,550 watts. Assuming that the building will use 400 Wpeak of PV, it is calculated that the number of panels needed is around 64–74 panels. Specifically, the PV that will be used is the Q-peak Duo L-67.3 brand with a monocrystalline quantum solar half-cell made in Germany, sized at 2015mm x 1000mm x 35mm (as seen in Fig. 5).

Figure 4. Site Plan of School of Citra Kasih (SCK) Citra Garden, Jakarta



MECHANICAL SPECIFICATION

Format	2015mm × 1000mm × 35mm (including frame)
Weight	23.0kg
Front Cover	3.2mm thermally pre-stressed glass with anti-reflection technology
Back Cover	Composite film
Frame	Anodised aluminium
Cell	6 × 24 monocrystalline Q.ANTUM solar half cells
Junction box	53-101mm × 32-60mm × 15-18mm Protection class IP67, with bypass diodes
Cable	4mm² Solar cable; (+) ≥1350mm, (−) ≥1350mm
Connector	Stäubli MC4-Evo2, Hanwha Q CELLS HQC4, Amphenol UTX, Renhe 05-8, JMTHY JM601A, Tongling Cable01S-F; IP68 or Friends PV2e; IP67

ELECTRICAL CHARACTERISTICS

POWER CLASS			385	390	395	400	405
MINIMUM PERFORMANCE AT STANDARD TEST CONDITIONS, STC[1] (POWER TOLERANCE +5W / −0W)							
Power at MPP[1]	P_{MPP}	[W]	385	390	395	400	405
Short Circuit Current[1]	I_{SC}	[A]	10.05	10.10	10.14	10.19	10.23
Open Circuit Voltage[1]	V_{OC}	[V]	48.17	48.44	48.70	48.96	49.22
Current at MPP	I_{MPP}	[A]	9.57	9.61	9.66	9.70	9.75
Voltage at MPP	V_{MPP}	[V]	40.24	40.57	40.90	41.23	41.56
Efficiency[1]	η	[%]	≥19.1	≥19.4	≥19.6	≥19.9	≥20.1
MINIMUM PERFORMANCE AT NORMAL OPERATING CONDITIONS, NMOT[2]							
Power at MPP	P_{MPP}	[W]	288.3	292.1	295.8	299.6	303.3
Short Circuit Current	I_{SC}	[A]	8.10	8.14	8.17	8.21	8.24
Open Circuit Voltage	V_{OC}	[V]	45.42	45.67	45.92	46.17	46.41
Current at MPP	I_{MPP}	[A]	7.53	7.57	7.60	7.64	7.67
Voltage at MPP	V_{MPP}	[V]	38.29	38.60	38.92	39.23	39.54

[1] Measurement tolerances P_{MPP} ±3%; I_{SC}; V_{OC} ±5% at STC: 1000W/m², 25±2°C, AM 1.5 according to IEC 60904-3 • [2] 800W/m², NMOT, spectrum AM 1.5

Figure 5. PV Specification(Beaudet, 2016)

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The next step is to calculate the area needed for those PVs. Because of the existing façade condition and the number of solar radiations received as simulated by HelioScope (Fig. 6), the PV will be integrated only on the roof facing northeast and northwest orientations. The available area here is around 134 m2 and fits 67 PV panels.

Figure 6. Simulation of Solar Radiation Received at SCK Citra Garden Roof

To calculate the energy output of BIPV, the loss factor must be determined first. The source of the loss factor is assisted by HelioScope software. It consists of shading (8.6%), reflection (2.7%), soiling (2.0%), irradiance (0.7%), AC System (0.3%), inverters (1.7%), wiring (0.2%), mismatch (4.9%), temperature (7.5%). The total loss factor, 113.32 watts, is a summary of the percentages of each source which is multiplied by the PV watt peak (see Table 1). This loss factor is reducing the PV output power, from 400 Wp to 286.68Wp. As calculated before, the number of PV fit to the existing roof is 67 panels. This means that the total PV output power is 19.208 Wp (PV output power multiplied by the number of PV panels).

To calculate the average energy per year, the total output power is multiplied by the number of days in a year (365) and the number of peak sun hours (4.57). From this calculation, it is known that the total energy per year generated by the BIPV system in this case is 32,039 watts. This number could substitute 16.26% of conventional electrical energy consumed by the building.

Table 1. Total Loss Factor Calculation

Source of System Loss System

Source of System Loss	System Percentages (%)	PV watt-peak (Wp)	Loss factor/ Source (watt)
Shading	8.6	400	34.4
Reflection	2.7	400	10.8
Soiling	2.0	400	8.0
Irradiance	0.7	400	2.8
AC System	0.3	400	1.2
Inverters	1.7	400	6.8
Wiring	0.2	400	0.8
Mismatch	4.9	400	19.6
Temperature	7.5	400	30
Total Loss Factor			113.32

Greenship has already set a standard to assess the performance of on-site renewable energy. They are 1 credit for 0.25% or 2kWp, 2 credits for 0.5% or 5kWp, 3 credits for 1.0% or 10kWp, 4 credits for 1.5% or 20kWp, and 5 credits for 2.0% or 40kWp. Based on the calculation above, the BIPV system at SCK Citra Garden could generate 16.26% electrical energy needed by the building. This means that the BIPV system at SCK Citra Garden meets the Greenship standard and deserves 5 credits from the rating tools.

The difference between the standard and the numbers achieved in the application is quite big. This could happen for several reasons. First, related to the building system. Greenship standard refers mostly to building with an active system with huge electrical consumption.

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The building was chosen as the study's subject, and in addition to its active system, its passive system was taken into consideration.. Its consumption energy index (163.35 kWh/m2 per year) is already lower than the baseline (240 kWh/m2 per year). This circumstance encourages a greater proportion of BIPV-generated electrical energy substitution.

The second factor primarily has to do with building typology. High-rise structures are often subject to the Greenhouse Standard. This type of building has a relatively smaller area on its roof compared to the mid-rise or low-rise building type. Larger areas on a roof (particularly for an existing building) give higher opportunities to install PV, receive solar radiation, as well as to generate electrical energy from a renewable energy source.

Conclusion

The study was conducted to determine whether or not efforts made to switch the electrical energy source to renewable energy have a significant value in terms of net zero buildings. To note the value, the on-site renewable energy output (BIPV power output) was calculated in percentages of the total electrical energy needed by the building. Even though the percentages of electrical energy output by BIPV are still below the target of the government's national energy mix, the results show that it already exceeds the Greenhouse Gas Standard. The highest credit from GBCI (5 credits) is given when renewable energy could supply a minimum of 2.0% of the electrical energy needed by the building. Here, the BIPV system in SCK Citra Garden supplies 16.26% of the total electrical energy needed by the building.

A limitation of this research is that the object is an existing building with boundaries of structure and elevation that have already been established without considering the integration of PV. The option to instal PV is then severely restricted to the roof area. Further research can be conducted by taking a building during the design phase so that the integration of PV has a larger option and the structure can be prepared from the start of the construction phase. In this case, the chance of on-site renewable energy covering the building's annual energy load will be much bigger, so the target of a "Net Zero Energy Building" will be achieved. This research can be expanded to a larger scale (urban area) by using the Greenship Neighborhood parameter.

Author's statement

The authors are with this declare that this research is free from conflicts of interest with any party, has never been published in any place and has complied with the rules of publication ethics.

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Author(s) Contributionship

Susan Susan contributed to Conceptualization, Conceived and designed the analysis; Collected the data; Contributed data or analysis tools; Performed the analysis; Wrote the paper.

Dyah Kusuma Wardhani Contributed to collecting the data (literature study); editing the paper.

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Yusuf Ariyanto as Project administration.

Daniel Martomanggolo Wonohadidjojo contributed in Performed the formal analysis.

Eric Harianto contributed in Collected the data (field observation, investigation)

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