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Building integrated photovoltaic as GREENSHIP'S on site renewable energy tool

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ABSTRACT

Building challenges energy production from various sources, since it consumes energy in each stage of its life. The electrical energy in Indonesia is mostly produced by fossil fuel, an unrenewable energy resources has led to negative impacts on the environment. Thus, the availability of this resource is getting less. Fortunately, Indonesia has abundant renewable energy resources, and the use of these resources are still a minimum. This fact is supported by the data that many of Green-certificated buildings in Indonesia failed to take credit for the on-site renewable energy in their assessment. This research presents the proposed case of Universitas Ciputra. A building which was designed with green features and has the potential for on-site renewable energy integration, particularly for solar energy with BIPV as its concept. The aim of this research is to observe efforts made for optimizing electrical energy production from the renewable energy resources, along with the amount of optimum electrical energy generated compared to Greenship standards. The PV panels were integrated to the building façade elements (roof, opaque wall, transparent wall, and shading device), using optimum tilt and orientation angle. The result shows that the application of BIPV concept could substitute for 6–22% of the maximum power demand needed. Thus, the BIPV application on the building roof alone, would already reach the Greenship target for on-site renewable energy tool.

1. Introduction

Providing electrical energy for a building's operational stage has been widely discussed from many aspects, particularly when the building conventionally consumes huge amount of electrical energy, both for HVAC and lighting. Recently, issue from relevant research shows that huge demand of electrical energy comes also from information and communication technologies (ICTs), which require up to 20% of the global electricity demand by 2030 [1]; pp. 1–10). The increasing demand from ICTs on building's operational stage comes from massive computational resources through large computing centers. Data shows that buildings consume about one-third of the world's energy [2]; pp. 300–315). This energy mainly produced from fossil fuel, unrenewable energy resources that act as the main contributor to global warming and climate change, which cause several damages.

In order to overcome this problem, there are three strategies that can be adopted. First, reducing energy consumption could be done by choosing energy-saving equipment and energy-saving management. Example is taken from energy saving based lighting system and smart control solutions for rail transportation in China [3]; pp. 1–12). Here, intelligent lighting control system which is adopted DALI digital light adjustment can meet the target of user comfort and energy saving solution. Another solution is increasing energy efficiency by converting waste energy into recovered energy. For example, by converting wasted heat from the cooling system into a recovered heating system for organic data center [4]; pp. 1–3). The third strategy proposed is switching to renewable energy resources. Relating to the third strategy, Indonesia has abundant renewable energy resources. The number reach 311.232 MW, consist of 94.3 GW hydropower, 28.5 GW geothermal, 207.8 GWp solar energy, 60.6 GW wind energy, 17.9 GW ocean energy, and 32.6 GW bioenergy ([5]; p. 6). However, only about 5% of this amount is utilized. Based on that data, the Indonesian Government has actually decided on a National Energy Mix Program. By 2025, the government set the target to mix the energy used as 30% from coal, 22% from oil, 25% from natural gas, and 23% from renewable energy. In this case, renewable energy that comes from the environment should interact with technology by providing the resources needed for technological development, and technology development should put concern on its environmental impact [1]; pp. 1–10). The interaction and the integration aim to reach positive impacts on Sustainable Development goals, particularly in the aspect of

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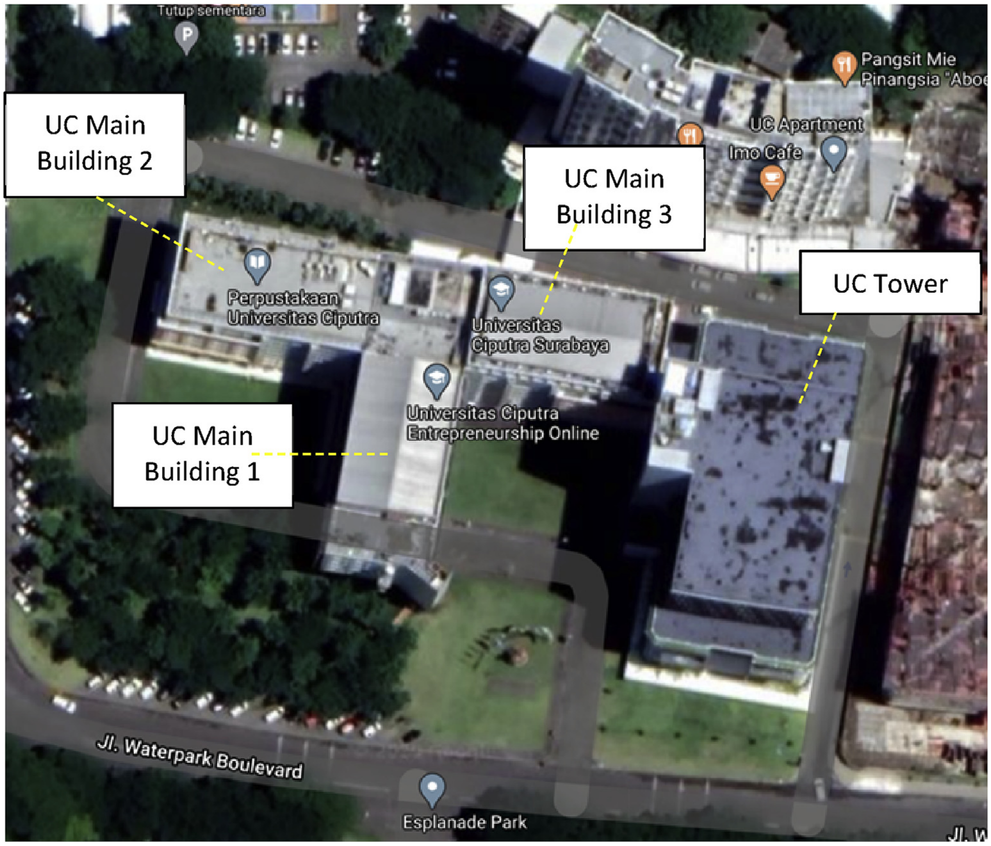


Fig. 1. UC site plan.

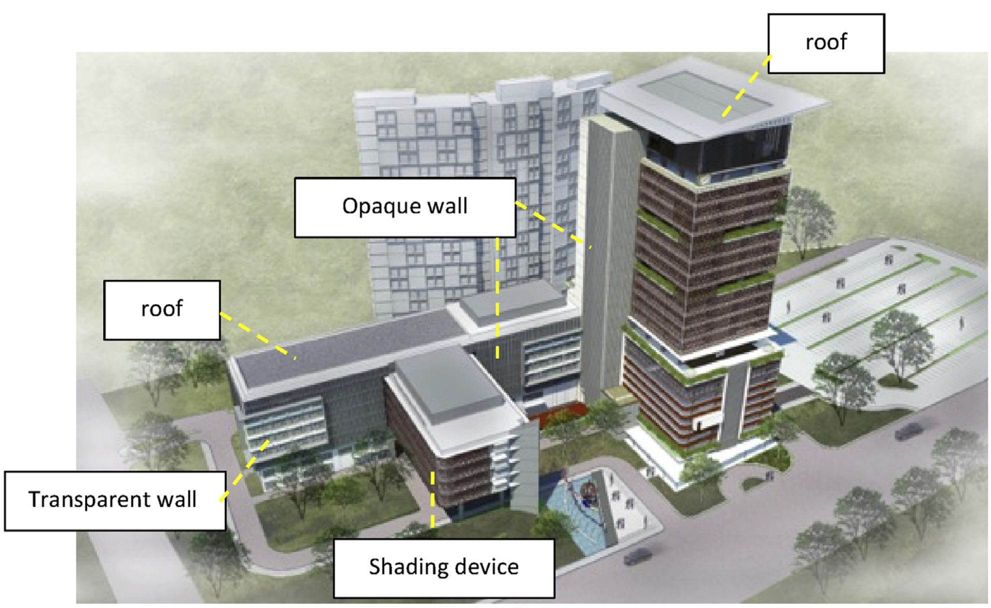


Fig. 2. PV placement alternatives.

Affordable and Clean Energy. There are two groups of technologies for converting renewable energy. First is on/in the building or on the ground attached to the building, and second is the system that is placed outside the building owner or the building owner just purchases the electrical energy that is produced by renewable energy resource [6]; pp. 154–165).

Independent institutions such as Green Building Council Indonesia (GBCI), set the Energy Efficiency and Conservation (EEC) as one of its rating tools. Totally, there are 6 criteria in this rating tool. One of them is on-site renewable energy. This parameter is set by GBCI to motivate the use of on-site renewable energy, aimed to minimize the use of fossil energy as well as reduce energy discharges that occur due to the distribution process. The parameters from GBCI are determined from the percentages of maximum power demand or numbers of electrical energy in kWp, that can be generated by renewable energy. The percentages range from 0.25% or 2 kWp (1 credit), 0.5% or 5 kWp (2 credits), 1.0% or 10 kWp (3 credits), 1.5% or 20 kWp (4 credits), and 2.0% or 40 kWp (5

Table 1
Electrical energy consumption in UC.

Bulan	2018 (kWh)	2019 (kWh)
January	71240	150440
February	127520	165300
March	167260	168500
April	152700	180840
May	131000	167340
June	84460	116380
July	117800	131960
August	173560	192880
September	151160	192740
October	190260	254480
November	189360	230860
December	96120	182420
Average	137703.33	177845

credits).

One of on-site renewable energy tool strategies is by using photovoltaic (PV). PV is potential microgeneration technology. PV produces electrical energy without pollution, from an abundant renewable energy resource, solar energy. Regarding to climate change and greenhouse gas emissions, PV systems described as the greenest source of energy to provide power for various remote and large-scale applications [7]; pp. 1–5). Commonly, the market knows there are three types of PV: Mono-crystalline, poly-crystalline, and amorphous. Mono-crystalline has the highest efficiency and is often used as wall cladding. Poly-crystalline and amorphous has less efficiency, and they often used as glass cladding. One of its installation systems is called building integrated photovoltaic (BIPV). BIPV provides more benefits because it can generate energy right on the site, right in the place where the energy needed, as well as reduce energy loss caused by the distribution process [8]; pp. 993–999). However, the performance of BIPV depends on some factors: the numbers of cells [9]; pp. 213–218), PV's efficiency [10]; pp. 77–84), temperature and solar radiation received [11]; pp. 2441–2452), tilt and orientation

Table 2
Area of façade elements.

Area	Orientation	Transparent wall (m2)	Opening (m2)	Opaque Wall (m2)	*Shading Device* (m2)	Roof (m2)
UC *Main Building* 1 (UC 1)	0°	106.16	20.00	563.84	0.00	300.45
	90°	368.20	0.00	733.80	608.00	
	180°	103.50	0.00	343.50	0.00	
	270°	368.20	0.00	733.80	608.00	
UC *Main Building* 2 (UC 2)	0°	377.38	0.00	1094.62	0.00	
	90°	26.84	0.00	363.16	0.00	
	180°	366.88	0.00	1105.12	0.00	
UC *Main Building* 3 (UC 3)	0°	362.87	0.00	1033.13	0.00	
	180°	122.16	0.00	607.84	0.00	
	270°	440.21	0.00	955.79	0.00	
UC *Tower*	0°	94.80	325.25	853.46	412.39	209.34
	90°	129.84	868.68	1111.99	486.87	
	180°	73.20	325.25	853.46	433.99	
	270°	367.14	476.86	1182.71	289.22	

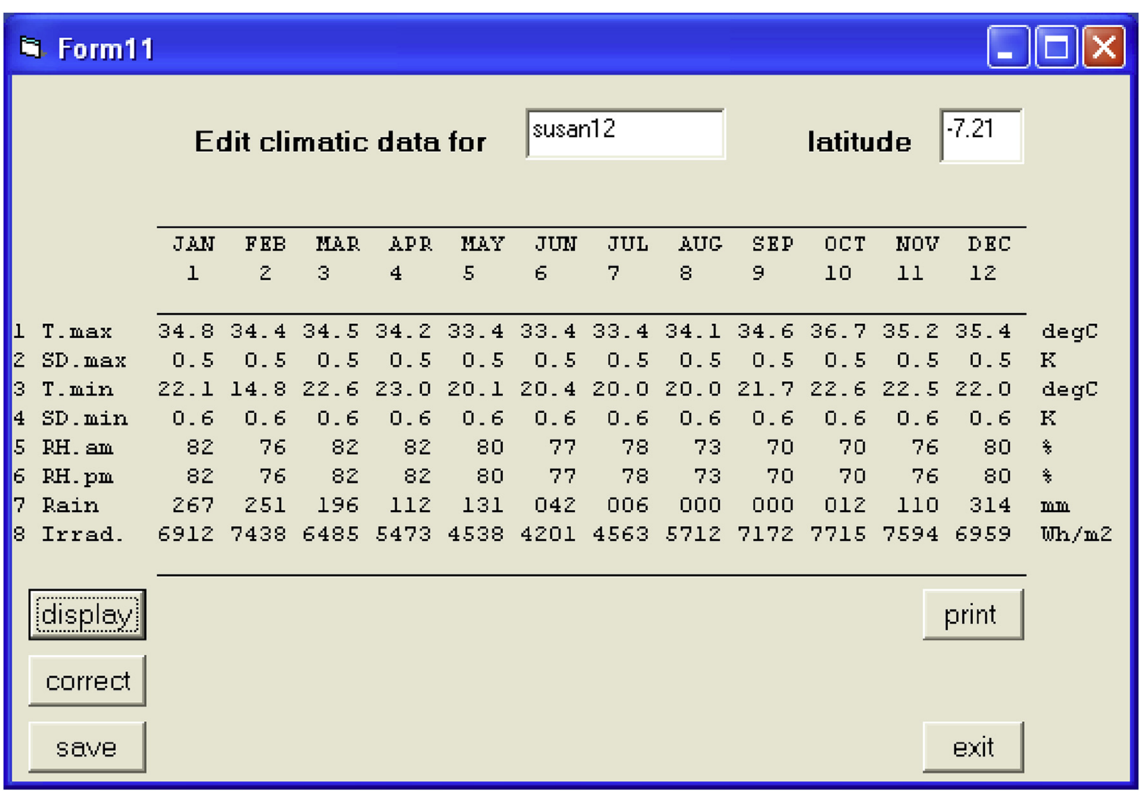


Fig. 3. Data inputted to the archipak 5.1 database.

Fig. 4. Simulation of solar radiation received for some of tilt and orientation angles proposed.

angle [11]; pp. 2441–2452 [12]; pp. 2468–2475 [13]; pp. 31–44 [14]; pp. 2107–2113), and shading condition [14]. Also, there is a discrepancy factor which refers to the error of the expected energy output compared to actual energy output [15]; pp. 2515–2523).

The number of cells influence the performance of BIPV, since it drives the voltage of electrical energy generated. The PV cells' number typically range between 36 and 216 cells, with 100Wpeak-300Wpeak. Smaller modules are preferable in the installation process since it is handier. The smallest module dimension is about 1184 mm × 545 mm x 35 mm. Efficiency in this term is a measurement of electrical energy generated, compared to the solar radiation received. Recently, the technology of PV has reached an efficiency number around 18.6%–19%. This efficiency number reached by PV was produced by Panasonic. PV will provide optimum performance if it works at 25 °C, receives 1000 W/m2. However, when PV receiving solar radiation, its temperature will rise and cause the difference between expected energy output and actual energy output. The discrepancy measured is about 6% [15]; pp. 2515–2523). An air gap could be an effective solution to maintain PV at the optimum temperature while receiving solar radiation [16]; pp. 1051–1057). The next influencing factors are the tilt and orientation angle. In BIPV, PV is usually installed at fixed angle, determined by incidence angle, geographical latitude, and buildings position whether in southern or

Table 3
Amounts of annual radiation received.

Code	Tilt (°)	Orientation (°)	Annual Radiation Received (kWh/m2)
(a)	(b)	©	(d)
R1	30	0	2082
R2	46	270	2317
	44	90	2301
WO.1	90	−15	2183
	90	15	1959
WO.2	90	45	2052
	90	135	2109
WO.3	90	225	2098
	90	315	2045
WT.1	90	0	2003
WT.2	90	90	2217
WT.3	90	270	2213

northern hemisphere. For PV installed at one fixed tilt angle (sawtooth model), tilt is determined the same as geographical latitude, or 20°–30° for areas at low latitude. Optimum orientation for PV is between −15° - 15° measured from horizontal plane, facing equator. For other cases in which the PV installed in two fixed tilt and orientation angles with a folding concept (particularly for areas near the equator like Indonesia), 46° & 44° is a pair of optimum tilt angle while the optimum orientation angle is 45° & 135° for East side, and 224° & 316° for West side. In case of rooftop PV installation in residential areas, glare from surrounding surfaces is also an important concern and mentioned as nuisance like noise, since there is a greater chance for solar reflections to travel towards the sky. Related to this issue, variation in PV module orientation is preferable, since it alter the direction of solar reflection and reduce the degree of glare impact [7]; pp. 1–5). Shading condition is another boundary of BIPV performance. It is divided into soft shading condition in which only 10% of diffuse solar radiation can be absorbed, and hard shading condition in which direct and diffuse solar radiation can't be absorbed by PV cell. However, 25%–30% is the average amount of power reduction in every shading conditions.

2. Research methodology

2.1. Site selection

This research proposes installation of BIPV at Universitas Ciputra (UC). UC located in the middle of residential and commercial area, on Surabaya, East Java province, Indonesia. The building's location is situated at 07°29 S Latitude, 112°63 E Longitude. The geographical location of UC indicates that the site has abundant solar irradiance, easy access and easy land availability. UC is part of the Ciputra Group, which was established by Dr. (HC) Ir. Ciputra in 1981. The Ciputra Group pioneered large-scale development with a sustainable concept in Indonesia. The UC Building consists of 2 main buildings, which were developed in two stages. The first stage is named UC Main Building 1, 2, 3, and the second stage is named UC Tower. The site plan of UC is shown in Fig. 1. The main entrance of the building face north orientation, and the shape extends east and west. As the response to the climate, the elongated side of the building faces north and south, while the short side of the building faces east and west. The layout is designed as shallow layout. Comparison of its length to its width range between 1:1.8–1:2. This design will passively reduce the thermal transfer value and reduce the cooling load needed by the building (see Fig. 2).

UC Main Building 1, 2, 3 consists of 7 floors. Classrooms, library, laboratory, student lounges, and staff's offices placed at 1st – 6th floor. While pre-function hall, theater and auditorium placed at 7th floor. UC Tower consist of 23 floors. Parking area on the 1st – 7th floor, communal area on the 8th floor, classroom at the 9th – 22nd floor, and multipurpose hall on the 23rd floor.

Based on some previous research, the design of the on-site renewable energy tool has some steps [17]; pp. 72–78). The design covers a mapping of current energy status, decreasing energy demand, and increasing the energy from RES. Related to this research, the current energy status is shown in Table 1. Related to decreasing energy demand, the UC Building already has green features such as vertical greenery system for the parking building, secondary skin on its east and west façade, OTTV calculation, inverter AC system, daylight utilization on parking area, and 100% electronic ballast for artificial lighting system. Those strategies were applied in order to reduce electrical energy consumption. However, the electrical energy still generated from State Electricity Company and the energy source still comes from unrenewable energy.

This research observes strategies that can be applied in order to switch to unrenewable energy resource, particularly through the using of BIPV as on-site renewable energy tool. The aim is to present the number of electrical energy, generated by BIPV as on-site renewable energy tool, and to present the BIPV performance as on-site renewable energy tool, measured by Greenship standard.

The UC building is studied for analyzing BIPV performance as on-site renewable energy tool according to the Greenship parameters. This research uses the experimental method, by giving treatments to building's façade elements. The treatments are the integration of PV to the façade elements (the roof, opaque wall, transparent wall, shading device). The area numbers of those elements are shown in Table 2, and Fig. 3 shows the schematic drawing for the PV placement.

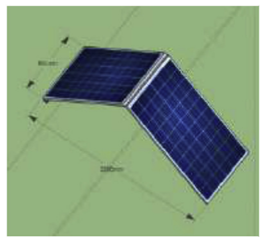
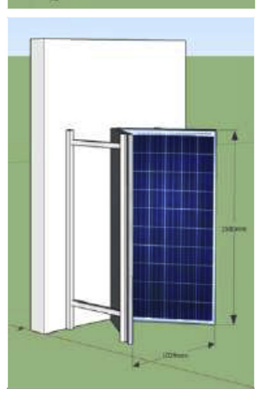
The tilt angle used for the proposed BIPV model for the roof is 30° (for the sawtooth model) and 46°–44° (for the folding model). While the orientation angle used for the opaque wall is 15°–15° facing the equator (for the north wall), 45° and 135° (for the folding model in the east wall), and 225° and 315° (for the folding model in the west wall). While the integration of PV in the transparent wall and shading device follows the existing tilt/orientation of the exisiting building. The treatments will create various potential areas to be proposed as BIPV models. Other factors such as the temperature, number of cells in a module, PV efficiency, shading condition become isolated variables and their values are considered constant. PV considered works in 25 °C temperature condition, 30% shading coefficient. Monocrystalline HIT silicone – 72 cells – 18.6% efficiency – 1580 mm × 798 mm x 35 mm, is used as proposed BIPV models at roof and opaque wall. Amorphous silicone – 15 cells – 19% efficiency – 1000 mm × 720 mm x 35 mm is used for proposed BIPV models at transparent wall and shading device. Those two types of PV are selected based on some consideration, such as high efficiency number, handy dimension, as well as their opaque and transparent character.

2.2. Archipak 5.1 software: solar radiation received

Simulation using Archipak 5.1 software is used as tool to get the amounts of solar radiations received from the proposed BIPV models. Archipak 5.1 has seven user programs which is supported by three database programs. The seven user programs are Climate, Climanal, Timelag, Suncalc, ACRSYS, Qbalance, and Harmon. Meanwhile the three database programs are CLIMDATA, MATDATA, and ELEMDATA. This research uses CLIMDATA, which is used to create, arrange, and print climate data file. The specific climatic data of Surabaya from 2014 to 2018 (consists of Tmax, sdMax, Tmin, sdMin, Tsd, Rham, RHpm, Rain, Irad) were inputted to the database (Fig. 3). The Tmax, sdMax, Tmin, sdMin, Tsd, Rham, RHpm, and Rain data were collected from Meteorology and Geophysics Agency. While Irad (irradiation numbers) calculated manually from the percentages of sunshine duration per month.

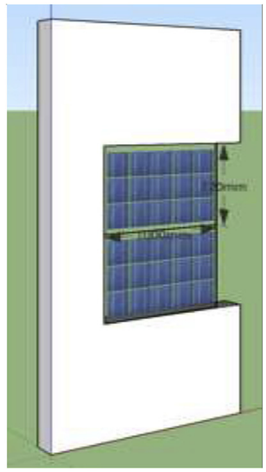
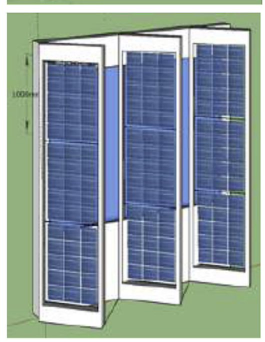
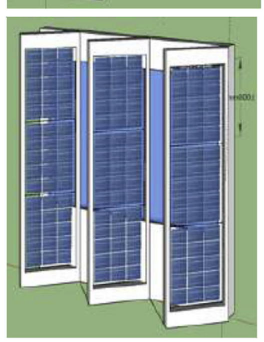
Simulation results data were taken for each month in a year (annual radiation received). Solar radiation calculated by Archipak 5.1 can be created in average day of 12 months. On this category, simulation could be run to generate solar radiation received by the building both for: direct and diffuse solar radiation received per hour by horizontal surface, solar radiation received per hour by vertical surface, global solar radiation on a sloping surface per hour, and daily global solar radiation on sloping

Table 4
Proposed BIPV models for UC building.

Area	Numbers of Potential Integrated Area (m2)	Code	Modelling	Tilt/Orientation (°)	Area per module (m2)	Numbers of PV Integrated Area (m2)
(a)	(b)		©	(d)	(e)	(f)
Roof	509.789	R1		30	1.13	509.63
		R2		46 (facing east) – 44 (facing west)	1.83	508.74
Opaque Wall (north)	3545.05	WO.1		−15 and 15	2.44	3542.88
Opaque Wall (east)	2208.95	WO.2		45 and 135	1.63	2208.65
Opaque Wall (west)	2872.30	WO.3		225 and 315	1.63	2872.06

(*continued on next page*)

Table 4 (*continued*)

Area	Numbers of Potential Integrated Area (m2)	Code	Modelling	Tilt/Orientation (°)	Area per module (m2)	Numbers of PV Integrated Area (m2)
(a)	(b)		©	(d)	(e)	(f)
Transparent Wall (North)	941.21	WT.1		0	0.79	940.89
Transparent Wall (East)	524.88	WT.2		90	0.79	524.56
Transparent Wall (West)	1175.55	WT.3		270	0.79	1175.52
Shading Device (East)	1094.87	SD.1		135	1.13	1093.84
Shading Device (West)	897.22	SD.2		225	0.81	896.67

surface for 12 months. A ground reflectance rate of 0.2 is used based on the assumption of homogeneous ground surface. Through this simulation, data of solar radiation received for each different tilt and orientation angle (sloping surface), were collected. As for example, Fig. 4 shows the simulation of solar radiation received, on average day of 12 months, for some of tilt and orientation angles proposed, in daily global, for 12 months. The results generated from this simulation is the amounts of annual radiation received per m^2, which will be multiplied with numbers of PV integrated area proposed, to generate the amounts of total annual radiation received.

The result of Archipak 5.1 simulation for each or tilt and orientation angles proposed are tabulated in Table 3.

3. Results and DISCUSSION

Based on the treatments explained above, modelling and its specification were created and tabulated on Table 4.

Data of annual radiation received (kWh/m^2) from Archipak 5.1 (Table 3) and numbers of PV integrated area in m^2 (Table 4) are then used to generate total electrical energy generated in kWh (Table 5).

In order to analyze the performance of proposed BIPV models, the numbers of electrical energy generated are compared to electrical energy consumption, and the percentage of substitution are calculated. Based on the calculation, the proposed models of BIPV could substitute 6–22% from maximum power demand needed (Fig. 5). As mentioned in the introduction, highest credits given by GBCI if percentage of maximum power demand or numbers of electrical energy in kWp reach 2.0% or 40 kWp. This number can be reached by R1 and R2 model, where PV is installed in roof area only. The roof actually has the most minimum potential area for PV integration. However, the roof integrated photovoltaic could meet the Greenship standard because they receive a high intensity of tropical solar radiation, where the sun's movement is dominant placed above the building. Both R1 and R2 model could substitute 6–7% from maximum power demand needed. However, R2 model is giving advantage regarding to glare issue. R2 model use folding concept with variation in PV module orientation (tilt and orientation

Table 5
Electrical energy generated.

Area Code	Orientation/ Tilt (°)	Numbers of PV Integrated Area (m^2)	Annual Radiation Received (kWh/m^2)	Annual Radiation Received (before shadow) (kWh)	Annual Radiation Received (after shadow) (kWh)	PV Efficiency (%)	Annual Electrical Energy Generated (kWh)	Electrical Energy Generated/ month (kWh)	Electrical Energy Generated/month with Discrepancy Factor (kWh)
R1	30	509.63	2082	1061049.66	742734.76	18.6	138148.67	11512.39	10821.65
R2	46	254.37	2317	589375.29	822276,46	18.6	152943.42	12745.29	11980.57
	44	254.37	2301	585305.37					
WO.1	−15	1771.44	2183	3867053.52	2706937.46	18.6	503490.37	41957.53	39440.08
	15	1771.44	1959	3470250.96					
WO.2	45	1104.33	2052	2266085.16	2429175.67	18.6	451826.68	37652.22	35393.09
	135	1104.33	2109	2329031.97					
WO.3	225	1436.03	2098	3012790.94	1586259.61	18.6	295044.29	24587.02	23111.80
	315	1436.03	2045	2936681.35					
WT.1	0	940.89	2003	1884602.67	1630322.38	19	303239.96	25269.99	23753.79
WT.2	90	524.56	2217	1162949.52	2108953.66	19	392265.38	32688.78	30727.45
WT.3	270	1175.52	2213	2601425.76	2055676.95	19	382355.91	31862.99	29951.21
SD.1	135	1093.84	2109	2306908.56	1319221.87	19	245375.27	20447.94	19221.06
SD.2	225	896.67	2098	1881213.66	814064.66	19	151416.03	12618.00	11860.92

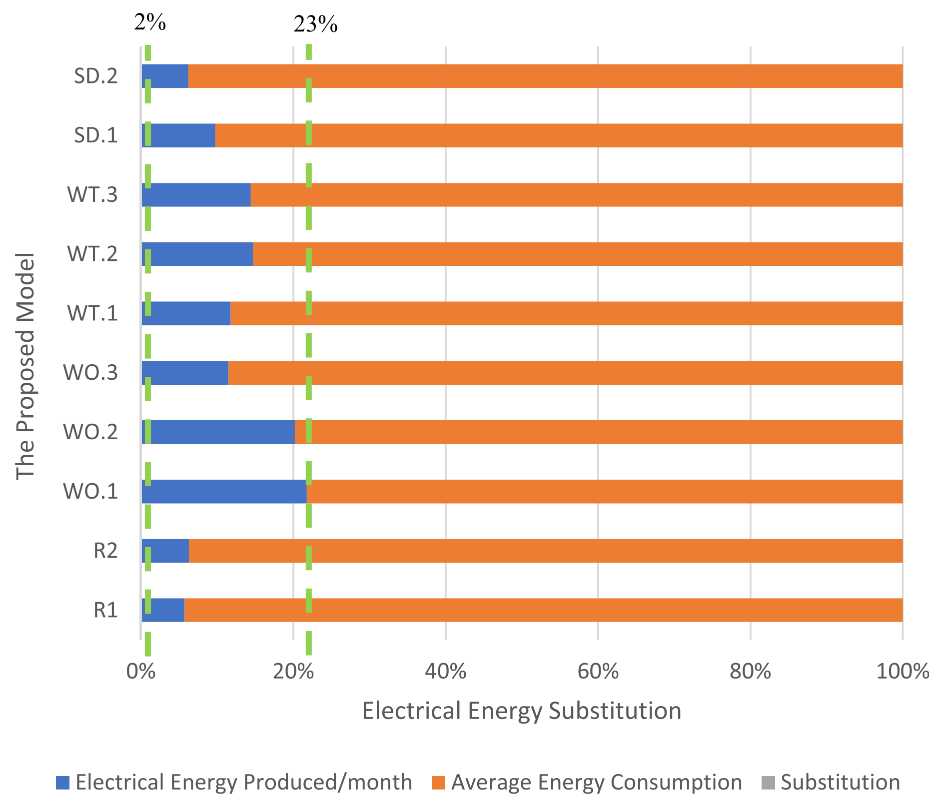


Fig. 5. Electrical energy substitution.

angle), which is preferable to mitigate glare impact [7]; pp. 1–5).

Additionally, if the result compared to the target of National Energy Mix Program, only WO.1 model could reach nearly to 23%. This model is using the folding concept on the north opaque wall. In fact, the WO.1 model actually generates the most electrical energy among other models. This happens because in this case the area of north opaque wall is the biggest among others. The potential available area itself will affect the amount of solar radiation received. The larger received area, the greater the amount of radiation received, and finally the greater electrical energy can be produced. Another reason is, wall integrated photovoltaic utilize the direction of relatively low angular value of solar radiation. In the tropics, low angular value of solar radiation is obtained at the beginning (east) and the end of the day (west). At this time, the radiation intensity is relatively low [18]; pp. 233–235). Based on these reasons, installing PV on the north wall is more profitable for building in a tropical area, in the southern hemisphere. This orientation will make PV able to capture solar radiation with the duration as long as possible, with the solar intensity as high as possible [10]; pp. 77–84).

4. Conclusion

This research was conducted to observe efforts made for optimizing electrical energy production from renewable energy resources, along with the number of optimum electrical energy generated compared to the Greenship standard. The final result of this study is the amount of electrical energy generation/solar radiation obtained by BIPV as an on-site renewable energy tool, the performance of BIPV as on-site renewable energy tool measured by Greenship standard, along with the suggestions for solar panel integration options at UC building. This research was conducted by making several assumptions. Solar cell temperature (25 °C), silicon type and color (HIT mono-crystalline PV for roof and opaque walls, amorphous silicon for transparent walls and shading devices), efficiency of PV modules (18.6%–19%). The discrepancy factor of 6% has been inputted in the research's calculation, in order to indicate the actual amounts of electrical energy generated.

The result shows that the proposed model on roof produces the lowest percentage of substitution, while the one on the north opaque wall produces the highest. The percentage of substitution on roof is 6–7%, and it meets the Greenship criteria to get 5 points, particularly on renewable energy sources on the site. The percentage of substitution on the north opaque wall reaches 22%, where this value nearly meets the government's energy mix target. This result shows that the proposed model of BIPV in the UC Building has the potential as an on-site renewable energy tool, both based on Greenship criteria and to achieve the government's energy mix target.

This research takes a building as its object, and does the assessment by using the parameter of Greenship for Existing Building. Further research are targeting on designing Net Zero Energy Building (Net ZEB), which is refers to the condition that on-site renewable energy generation covers the annual energy load [19]; pp. 381–391). This research could also be expanded into larger scale (urban area), by using the parameter of Greenship for Neighborhood. In order to have larger scale of research, city mapping are needed. The city mapping should cover the energy demand and the buildings' character. Compared to residential areas, public buildings such as commercial spaces, offices, hospitality could be the one assumed with higher energy demand. However, those public facilities, particularly those on high rise and low rise buildings could be proposed as potential BIPV models. High rise buildings typically have huge vertical areas, while low rise buildings typically has huge horizontal areas. Those areas are potential to be integrated with PV, to produce electrical energy both for the building itself as well as for small buildings around it.

Credit author statement

Susan: Conceptualization, Methodology, Software, Analysis, Writing - original draft, Writing-Reviewing and Editing, Supervision. Dyah Kusuma Wardhani: Preparation, Data curation, Visualization, Project administration.

Declaration of competing interest

- Abundant renewable energy sources in Indonesia, only about 5% is utilized.
- Abundant renewable energy sources, but many of Green certificated buildings in Indonesia failed to take the credit of on-site renewable energy in their assessment.
- Education facilities with green features, aimed to reduce energy consumption, but all the energy consumed comes from unrenewable sources and there is no effort to switch to renewable energy sources.

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