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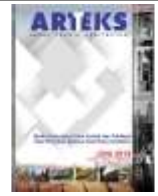

Research paper

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Optimizing integrated PV systems in buildings to reduce energy use

Case study: RSUP. NTB

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ABSTRACT

Energy efficiency is important in saving energy needs and reducing budget funds for hospital operations. There needs to be an effort to save energy using renewable solar energy sources. This study aimed to determine the optimal energy gain, the Break Event Point value, and the PV efficiency on the facade and roof of the RSUP Trauma Center NTB. It was conducted using a simulation method with the Rhino Grasshopper application and Open Studio Sketchup. It also involved collecting data and creating 3D input models into the Grasshopper and Open Studio plugin. The next stage was simulating OTTV, Cooling Load, and Photovoltaic in the test room within a year. The optimal PV shading based on the simulation was applied to the facade of the Trauma Center building. The results showed that laying PV on the roof would be more effective within 20 years than on the façade. This is because the efficiency value on the roof is higher than on the facade. The PV system measuring at a distance of 0.8 m on the facade and roof is 4.21% and 8.82% efficient, respectively. The efficiency at a distance of 1 m on the façade and roof is 6.31% and 7.81%, respectively.

Introduction

Global energy consumption is estimated to increase by 48% in 20 years between 2020 and 2040 (Mols and Blumberga 2020). Indonesia is a developing country with an annual population increase, which increases the human need for electrical energy (Notodipuro and Mandala 2022). Scientists have predicted that non-renewable energy sources, such as natural gas, oil, and coal, would become increasingly scarce in the next few years (Seputra 2018; Prastyatama and Maurina 2018). This would significantly impact energy consumption. Therefore, this necessitates alternative renewable energy sources and applying energy efficiency strategies in every development plan. Indonesia contributes 44% of the energy needs in Southeast Asia, followed by Thailand and Malaysia at 23% and 20%, respectively. Fossil, non-renewable energy is predicted to dominate energy demand in Southeast Asia, reaching 80% in 2030. This would exceed the 2011 realization of 76% based on the ASEAN Center for Energy Data (Putri, Siam, and Nugroho 2019).

Data from the Japan International Cooperation Agency (JICA) in the Study of Electricity Use in Multiple Jakarta Buildings showed that ventilation uses more electrical energy, followed by the lighting system in buildings. Hospitals consume 16% of electrical energy in the lighting system, while the air-cooling system uses 57%.

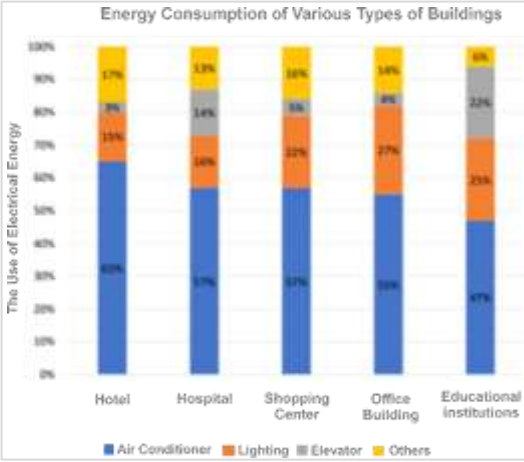


Figure 1. Energy Demand in Southeast Asia 2010-2035
Source: (International Energy Agency 2019)

The need for electricity in the RSUP NTB building increases yearly. In 2019, the average energy use in the RSUP building was 392,600 Kwh. This value increased to 480,403 Kwh in 2020 and 512,152 Kwh in 2021 (PLN NTB 2021).

Figure 2. Energy needs at RSUP NTB
Source: (PLN NTB 2021)

The annual increase in energy is a major problem in the RSUP NTB building. This requires an alternative solution to reduce the annual energy use. Applying the Integrated PV system could reduce the use of electrical energy from PLN. Energy efficiency is important in saving energy needs and reducing budget funds for hospital operations.

This study aimed to determine the optimal energy gain with the PV system on the roof and facade of the RSUP NTB. It intended to determine the Break Event Point (BEP) value for each PV configuration and the most efficient PV configuration within 20 years.

The West Nusa Tenggara region has great potential for solar energy development. The constant solar radiation is 12 hours/day in the year and could be classified as having a high intensity. The average global annual solar radiation is equivalent to 4.99kWh/m^2 or 17.98MJ/m^2, and 5.47 kWh/m^2 or 19.69 MJ/m2 for NTB. This high potential could be utilized in government, schools, offices, and hospitals. Utilizing renewable energy in building construction would benefit human survival. Non-renewable energy sources would increasingly decrease and run out, necessitating development planning using renewable energy in the future. Therefore, this study could help develop Integrated PV designs to optimize unlimited and environmentally friendly renewable energy sources.

BIPV

Several studies have been conducted on PV systems on facades and roofs. Freitas et al. (2020) examined modeling and assessed BIPV envelopes using parametric Rhinoceros plugins Grasshopper and Ladybug. The study found that the surface that allows for installing BIPV applications on institutional buildings in the central Brasilia zone produces the effect of shadowing by neighboring buildings, tall trees, or even the building's geometry. BIPV systems on facade surfaces only cover between 2.66% and 10.56% of the energy balance, with a higher proportion for taller buildings in sloping PV shading devices. Vertically regulated BIPV occupies more surface area, enabling higher nominal power. In contrast, simulation results for BIPV roof applications are less favorable, specifically for buildings six stories high, achieving higher than 50% of the annual energy balance. Regarding the different roof arrangement tests, the North and East/West orientations were conducted almost similar, with a difference of less than 5% for energy generation. From an energy generation perspective, the results support previous work, highlighting the importance of assessing the influence of shadows in urban environments. The results also suggested that BIPV systems in warm and sunny countries such as Brazil help achieve energy efficiency goals, such as the ZEB concept.

The combination of the inclination and orientation angles would greatly affect the BIPV System as a giver of architectural form and a power generator. The angles would make the BIPV system configuration. Obtaining higher power output from BIPV requires considering certain factors, such as PV slope, shading effect, and building temperature and direction (Abdullahi et al. 2021; Tripathy et al. 2017). It is also important to select a surface with high radiation with a wider facade than the roof (Aguacil, Lufkin, and Rey 2019). The optimal angle of inclination is equal to the latitude angle. However, the low inclination angle for low latitude areas would not be effective because dust would cover the PV surface. Hussein, Ahmad, and El-Ghetany (2004) found that the optimal range of inclination and orientation angles for low latitude areas is between 20°-30° and 15° to 15° facing the equator, respectively.

Susan, Antaryama, and Noerwasito (2015) conducted an Integrated Configuration of Folding Roof-Bipv and Its Optimation at an Office Building in Surabaya. The results showed that the electrical energy from the folding roof-BIPV exceeds that produced by the flat roof-BIPV. East-West orientation with a tilt angle of 45⁰ is the optimal configuration because it receives the highest daily solar radiation in the year. Moreover, it has the highest uniformity of the annual radiation received. This conclusion supports the theory developed by Bonifacius (2012). The electrical energy generated by the BIPV-folding roof in an east-west orientation at 45⁰ could produces 25.17kWh/m²/year. This figure could replace 10.5% of the electrical energy needed from fossil fuels.

Sun shading

Sun shading bars sunlight from directly entering the room. The shade is also used as an aesthetic element in the building to block the incoming heat due to sunlight (Purnama 2020). The horizontal Sun Shading Device is more effective in the ITDC Office Tower Semarang Design. It provides a more optimal energy-saving value than Vertical Sun Shading (Fikri 2020). Shading devices using PV panels block the incoming solar heat and produce renewable energy for buildings. Horizontal BIPV shading obtains optimal energy than vertical BIPV shading configurations and is better in reducing thermal loads in buildings (Asfour 2018). Using a building envelope could remove 40% of the heat load in a building (Yan et al. 2019).

Method

This study employed a simulation method using the Rhino and Sketchup applications. The method makes a copy of reality and represents how something could occur, not how it should be. Moreover, simulations represent a system's behavior against other systems, specifically computer programs designed for a particular purpose (Atthaillah, Bakhtiar, and Badriana 2019). The first stage of this study was collecting data and making 3D input models into the grasshopper plugin. The second stage simulated OTTV, Cooling Load, and Photovoltaic in the test room within a year. The third stage involved conducting a photovoltaic energy simulation in the Covid Trauma Center building, RSUP NTB.

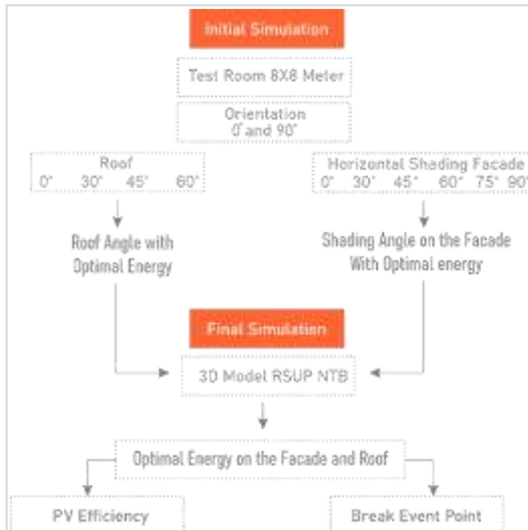


Figure 3. Simulation stage

One type of fabric used in the present study is cotton. This specific material is chosen because this material can absorb water well and has high saturation efficiency, as the previous research indicated (Velasco-Gómez et al. 2020). A material can absorb more water, and its evaporative cooling performance is better. The study selected the material due to its wide usage in everyday or domestic clothing or purposes. There are three different cotton specifications considered in the study. The first is cotton used for a blanket, the second for batik base, and the last for a towel. These three materials are different in weight, thickness, and texture. Table 1 lists the characteristics of these three fabrics and the control model set for the experiment.

Initial simulation

The simulation stage determined the orientation that evaluates the PV shading performance appropriately. Therefore, this stage is referred to as orientation simulation. It involves rotating the test room model and the facade in the North, East, South, and West directions. Each orientation simulates the value of OTTV, Cooling Load, and Photovoltaic Energy against the PV Shading configuration. Using PV shading on the façade is expected to generate energy and reduce the OTTV value in the building. This blocks the incoming heat due to sunlight (Purnama 2020).

The test room model used in this study is 8 m long, 8 m wide, and 8 m high. The side with high sun exposure potential has an opening with a Window to Wall Ratio (WWR) of 99%. The size of the PV panels is monocrystalline specifications with high efficiency and good aesthetics. The width of the PV is 80 cm, and the length of the panel follows the model of a test room with a length of 8 m.

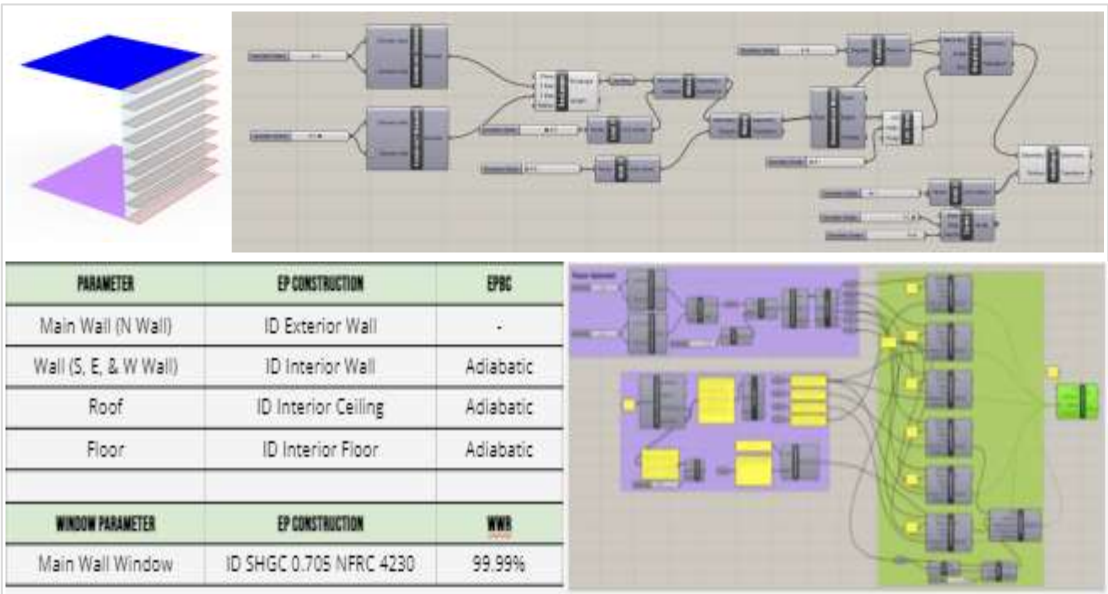


Figure 4. Test room models

The test room model has openings directly adjacent to the outside space, and the floor is adjacent to the ground, as well as part of the ceiling and the other sides besides openings bordering other spaces. It is an adiabatic plane model without heat and mass transfer between the system and its surroundings, except for the opening and the floor.

The simulation properties are needed to obtain accurate results according to the study objectives.

Table 1. Simulation properties

Properties	Specification
EPW	Mataram
Glass type	SHGC 0.7
Equipment load/area	10 W/m^3
Lighting density/area	3 W/m^2
People/area	0.1 Ppl/m
Ventilation/area	0.000305 $m^3/s\text{-}m^2$
Ecirculated air/area	0.00236/$m^3/s\text{-}m^2$

The shape was simulated on a test room model with parameters such as Angle and Distance.

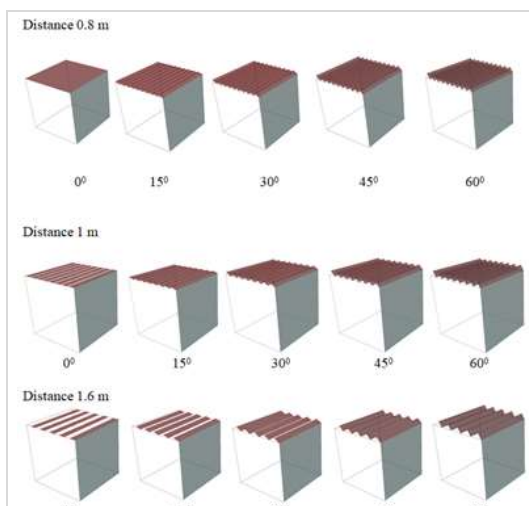


Figure 5. Roof test room models

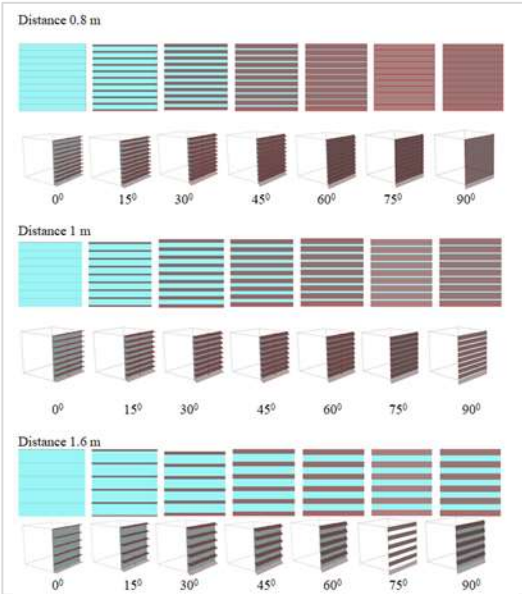


Figure 6. Façade test room models

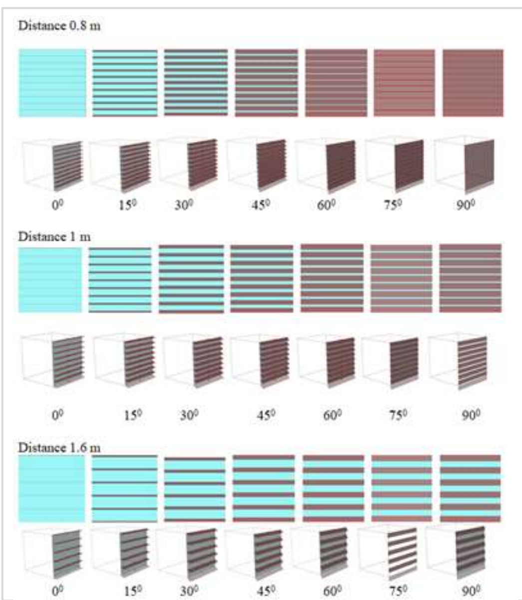


Figure 7. OTTV and cooling load simulation

This simulation was conducted to determine the best orientation on the facade for optimal PV placement by obtaining an Ottv value below 35 W/m^2 according to SNI 6389:2011 (Hariyadi, Fukuda, and Ma 2017) with the greatest energy gain.

Final simulation

This stage involved applying PV Shading on the RSUP building facade through photovoltaic energy simulation. It used a test model leading to the orientation specified in the initial simulation. The final simulation period used a full year span and followed Indonesia's general working hours between 08:00 and 17:00. Furthermore, it used Open Studio Sketchup with a cell efficiency of 15% using a monocrystalline panel. The results were analyzed as a reference to determine the PV shading performance. They also helped determine the shading configuration with the best performance on energy efficiency.

The energy in buildings was calculated using the energy plus engine software. This softaware was used by Anantama and Hariyadi (2021); Freitas et al. (2020); Hariyadi, Fukuda, and Ma (2017); Hoseinzadeh et al. (2021); and Kamel (2021). The studies used ladybug honeybee as an interface between the models made in grasshopper for simulation in energy plus.

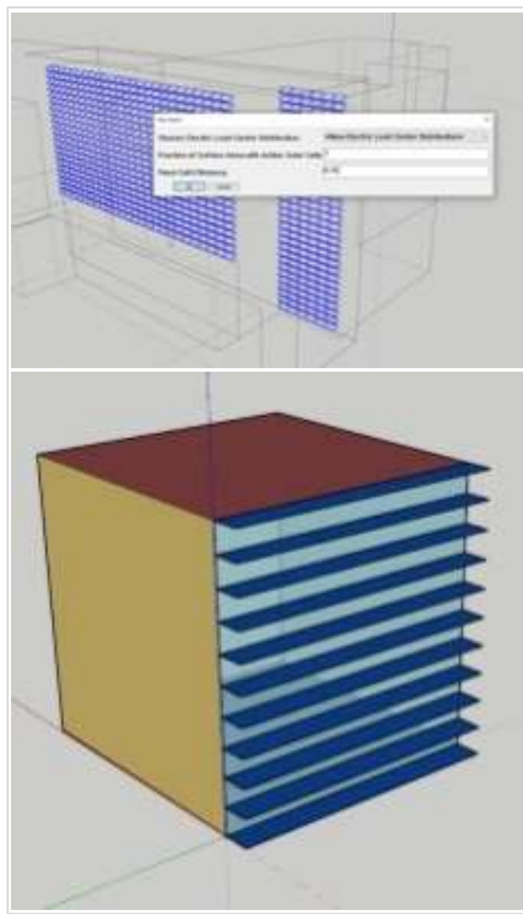


Figure 8. Photovoltaic simulation

Result and discussion

Photovoltaic shading simulation in test room

This simulation was conducted to determine the best orientation on the facade for optimal PV placement by obtaining an Ottv value below 35W/m^2 with the largest energy gain.

In the test room model with PV shading facing north at a distance of 0.8 m produced optimal energy at 45^o, with OTTV and energy gain of 31.58 watt/m^2 and 40,299 Gj, respectively. The shading at 1 m produced optimal energy at 50^o, with OTTV and energy gain of 33.52 watts/m^2 and 37.874 Gj, respectively.

Table 2. North facade simulation in the test room

Horizontal facade					
Test room	**Distance**	**Angle**	**OTTV (w/m^2)**	**Cooling Load (kwh/m^2)**	**Energy (Gj)**
	0.8	0	52.06	255.47	38.979
		15	48.29	243.84	40.023
		30	44.83	232.62	40.428
		45	**31.58**	**186.55**	**40.299**
		60	20.26	147.84	39.216
		75	12.3	119.36	36.762
		90	7.38	96.86	33.081
	1	0	54.34	262.2	37.242
		15	46.15	235.19	38.221
		30	39.52	213.17	38.514
		45	35.24	198.82	38.184
		50	**33.52**	**192.52**	**37.874**
		60	30.8	183.77	36.708
		75	28.98	177.62	34.085
		90	41.44	214.94	29.773
	1.6	0	77.43	339.52	31.998
		15	70.91	318.56	33.291
		30	66.65	304.75	33.463
		45	59.44	279.27	32.457
		60	55.97	265.69	29.467
		75	60.18	277.18	25.072
		90	74.17	321.26	19.849

In the test room model with PV shading facing east at a distance of 0.8 m produced optimal energy at 40^o, with OTTV and energy gain of 34,624 watt/m^2 and 41,624 Gj, respectively. In contrast, the shading at 1 m produced optimal energy at 50^o, with OTTV and energy gain of 33.68 watt/m^2 and 37,199 Gj, respectively. It implies that PV shading with a distance of 1.6 m reduces OTTV gain in the test room. This is seen from the high OTTV gain, where the lowest value in the test room is 63.78 watt/m^2. The value is far from the SNI standard that must be achieved.

Table 3. East facade simulation in the test room

Horizontal facade					
Test room	**Distance**	**Angle**	**OTTV (watt/m^2)**	**Cooling Load (kwh/m2)**	**Energy**
	0.8	0	61.17	293.86	46.971
		15	51.09	257.25	45.852
		30	44.22	233.93	43.237
		40	**34.42**	**199.85**	**41.624**
		45	29.77	183.74	40.856
		60	18.63	144.92	38.698
		75	11.47	117.25	37.595
		90	7.38	96.84	34.485
	1	0	68.57	319.72	43.03
		15	54.45	268.85	42.058
		30	43.45	230.26	39.92
		45	36.61	206.53	37.89
		50	**33.68**	**196.58**	**37.199**
		60	31.28	188.41	35.826
		75	29.56	182.24	34.323
		90	42.03	224.04	31.037
	1.6	0	93.41	410.02	34.354
		15	84.39	375.93	33.6
		30	77.92	352.48	31.817
		45	68.82	319.28	29.798
		60	63.78	300.61	27.243
		75	65.99	307.62	24.504
		90	77.35	346.84	20.691

In the test room model with PV shading facing south at a distance of 0.8 m produced optimal energy at 40^o, with OTTV and energy gain of 33.65 watt/m^2 and 34.137 Gj, respectively. The shading at 1 m produced optimal energy at 40^o, with OTTV and energy gain of 34.28 watt/m^2 and 31,223 Gj, respectively. It mens that PV shading with a distance of 1.6 m is less effective in reducing OTTV gain in the test room. This is seen from the high OTTV gain, where the lowest value in the test room is 43.49 watt/m^2. The number is far from the SNI standard that must be achieved.

Table 4. South facade simulation in the test room

Horizontal facade					
Test room	**Distance**	**Angle**	**OTTV (watt/m^2)**	**Cooling Load (kwh/m^2)**	**Energy**
	0.8	0	47.38	240.84	38.977
		15	44.79	232.65	38.716
		30	42.38	225.17	36.735
		40	**33.65**	**194.81**	**34.137**
		45	29.1	179.02	32.489
		60	18.47	142.72	27.035
		75	11.31	115.65	25.046
		90	7.38	96.83	22.95
	1	0	49.9	249.99	37.222
		15	43.41	226.89	36.551

Horizontal facade					
Test room	Distance	Angle	OTTV (watt/m²)	Cooling Load (kwh/m²)	Energy
		30	37.39	206.77	33.757
		40	**34.28**	**196.37**	**31.223**
		45	33.45	193.62	29.604
		60	29.21	179.19	24.629
		75	26.51	169.93	22.542
		90	31.46	186.04	20.655
	1.6	0	63.09	295.68	31.996
		15	60.49	287.09	30.374
		30	58.27	279.51	27.409
		45	51.25	254.92	23.736
		60	45.45	234.65	19.322
		75	43.49	227.34	16.891
		90	50.2	248.73	13.769

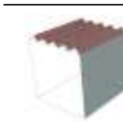
In the test room model with PV shading facing west at a distance of 0.8 m produced optimal energy at 45°, with OTTV and energy gain of 30.95 watt/m² and 44,388 Gj, respectively. The shading at 1 m produced optimal energy at 55° with OTTV and energy gain of 34.5 watt/m² and 39,936 Gj, respectively. It shows that PV shading with a distance of 1.6 m is less effective in reducing OTTV gain in the test room. This is seen from the high OTTV gain, where the lowest value in the test room is 71.78 watt/m². The number is far from the SNI standard that must be achieved.

Table 5. West facade simulation in the test room

Horizontal facade					
Test room	Distance	Angle	OTTV (watt/m²)	Cooling Load (kwh/m²)	Energy
	0.8	0	69.24	300.67	46.977
		15	55.75	262.5	47.53
		30	46.75	236.88	46.178
		45	**30.95**	**183.64**	**44.388**
		60	19.2	143.27	42.456
		75	11.78	116.6	41.469
		90	7.38	96. 83	38.036
	1	0	78.68	327.94	43.05
		15	60.95	273.59	43.558
		30	47.81	233.68	42.538
		45	39.56	208.64	41.059
		55	**34.5**	**192.26**	**39.936**
		60	33.53	189.25	39.295
		75	31.86	181.92	37.804
		90	46.12	220.79	34.233
	1.6	0	106.3	416.12	34.353
		15	95.48	382.46	34.625
		30	87.29	357.11	33.642
		45	77.26	322.89	32.018
		60	71.78	302.36	29.671
		75	74.34	307.24	26.876
		90	86.91	344.48	22.821

The roof test room model produced optimal energy at 0°. At this slope, there would be a risk of dust accumulation on each photovoltaic panel, reducing the panel's effectiveness in electrical energy production. The simulation was continued by reducing the inclination angle every 5°. This was intended to find the optimal energy and ensure that dust cannot accumulate and fall from the PV panel. The optimal slope with a PV distance of 0.8 m at 5° with an energy production of 80,029 Gj faces North. Additionally, a PV distance of 1 m produces 66,987 Gj of energy with a slope of 10° facing north.

Table 6. Roof simulation facing North in the test room

Roof					
Test room	Distance	Angle	Energy	Angle	Energy
	0.8 m	0	80.915	0	80.915
		15	77.54	5	80.029
		30	72.154	10	78.892
		45	64.561	15	77.54
		60	54.514	20	-
	1 m	0	66.228	0	66.228
		15	66.549	5	66.914
		30	62.632	10	66.987
		45	55.691	15	66.549
		60	46.302	20	-
	1.6 m	0	44.152	0	44.152
		15	44.775	5	44.678
		30	42.684	10	44.906
		45	38.266	15	44.775
		60	31.995	20	-

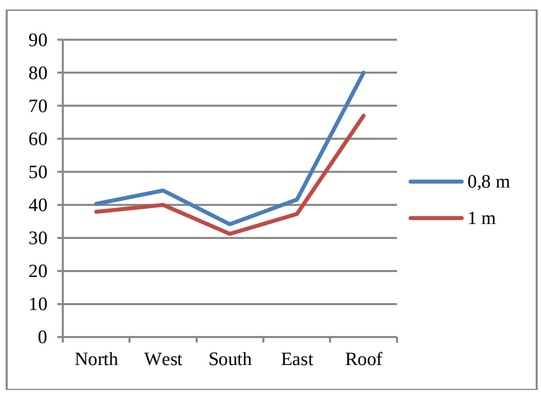


Figure 9. The room energy gain

In the test room, optimal energy was obtained in the facade and roof areas with a PV configuration of 0.8 m facing west at 45º and 5º, respectively. Optimal energy gain on the facade is based on the highest energy gain with an OTTV value below 35 watt/m^2. The optimal value on the roof area is also based on the highest energy gain.

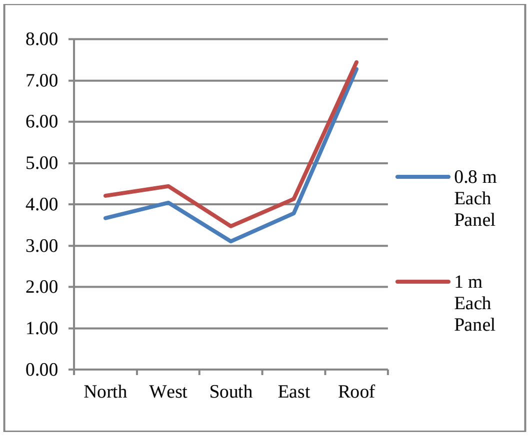


Figure 10. Energy gain on each panel in the test room

The decrease in energy gain in the facade configuration in the north, west, south, east, and the roof was 0.13%, 0.09%, 0.11%, 0.08%, and 0.02%, respectively.

The optimal configuration was applied to building on the facade and roof of the RSUP NTB Trauma Center building.

Photovoltaic shading simulation on the Trauma Center RSUP NTB Building

In the northern facade model of the Trauma Center Building, PV panels were placed in each opening at 45º and a distance of 0.8 m. This configuration produces 89,204 Kwh of energy in a year with 442 PV panels.

Figure 11. PV simulation on North facade 0.8 m

In the configuration on the north facade of the Trauma Center Building, a PV panel was placed in each opening at 50º and a distance of 1 m. This configuration produces 92,248.7 Kwh energy in a year with 442 PV panels.

Figure 12. PV simulation on North facade 1 m

The energy produced with a PV panel distance of 1 m is higher than a panel configuration at 0.8 m. The energy gain at 0.8 m and 45º produces 89.204 Kwh due to the shading effect of each PV panel. A relatively close PV distance could reduce the PV panel's efficiency. This is in line with Freitas et al. (2020) modeling and assessing BIPV envelopes using parametric Rhinoceros plugins Grasshopper and Ladybug. The study found that the surface used for BIPV applications on buildings in the middle zone of Brazil showed a pronounced shadow effect by the surrounding buildings, fairly high vegetation, and shading and panels caused by the building geometry. The BIPV system on the facade surface only reaches between 2.66% and 10.56%.

In the western facade model of the Trauma Center Building, PV panels were placed in each opening at 45º. The panels were placed at 15º and 0.8 m on the facade without openings. This configuration produces energy of 108,939.5 Kwh annually with 603 PV panels.

Figure 13. PV simulation on West facade 0.8 m

In the configuration on the western facade of the Trauma Center Building, PV panels were placed at 55º in each opening. They were placed at 15º and 1 m on the facade without openings. This configuration produces 99,815.9 Kwh energy in a year with 498 PV panels.

Figure 14. PV simulation on West facade 1 m

The energy generated on the West facade with a PV panel distance of 0.8 m is higher than at 1 m. This is proportional to the amount of PV used. Regarding the energy gain on each panel, PV with a distance of 1 m is more efficient because it obtains 200.43 Kwh, exceeding 180.66 Kwh produced at 0.8 m. Therefore, the shading effect on each panel greatly affects the PV energy output.

In the southern facade model of the Trauma Center Building, PV panels were placed in each opening at 40º and 0.8 m. This configuration produces energy of 57,930.9 Kwh annually with 372 PV panels.

Figure 15. PV simulation on South facade 0.8 m

In the configuration on the southern facade of the Trauma Center Building, a PV panel was placed at 40º and 1 m in each opening. This configuration produces energy of 57,774.2 Kwh annually with 348 PV panels.

Figure 16. PV simulation on South facade 1 m

The energy generated on the South facade with a PV panel distance of 0.8 m is higher than at 1 m. This is proportional to the amount of PV used. Regarding the energy gain on each panel, PV with a distance of 1 m is more efficient because it obtains 166.02 Kwh, exceeding 155.73 Kwh produced at 0.8 m. Therefore, the shading effect on each panel greatly affects the PV energy output.

On the east facade of the Trauma Center Building, PV panels were placed in each opening at 40º. On the closed facade, they were placed at 0º and 0.8 m. This configuration produces energy of 115,764.3 Kwh in a year with 654 PV panels.

Figure 17. PV simulation on East facade 0.8 m

In the configuration on the east facade of the Trauma Center Building, PV panels were placed at 50º in each opening. On the closed facade, they were placed at 0º and 1 m. This configuration produces energy of 104,317.3 Kwh annually with 528 PV panels.

Figure 18. PV simulation on East facade 1 m

The energy produced in the east facade with the PV panel distance of 0.8 m is higher than at 1 m. This is proportional to the amount of PV used. Regarding the energy gain on each panel, PV with a distance of 1 m is more efficient because it obtains 197.57 Kwh, exceeding 177.01 Kwh produced at 0.8 m. Therefore, the shading effect on each panel greatly affects the PV energy output.

On the roof model of the Trauma Center Building, PV panels were placed on the roof area at 5º facing north, with a distance of 0.8 m. A distance of 1 m was left to facilitate circulation access for PV maintenance. This configuration produces 190.089.04 Kwh of energy in a year with 604 PV panels.

Figure 19. PV simulation on roof facing Nort 0.8 m

In the configuration on the roof of the Trauma Center Building, PV panels were placed at 10º facing North with a distance of 1 m. This configuration generates the energy of 164,780.69 Kwh in a year with 512 PV panels.

Figure 20. PV simulation on roof facing Nort 1 m

The energy generated with a PV panel distance of 0.8 m exceeds that generated at 1 m. This is the highest value among configurations in each direction of the facade and other roofs. It is proportional to the amount of PV used. Regarding the energy gain on each panel, PV with a distance of 1 m is more efficient. It produced 321.84 Kwh, exceeding 314.72 Kwh obtained at 0.8 m. Therefore, the shading effect on each panel greatly affects the PV energy output.

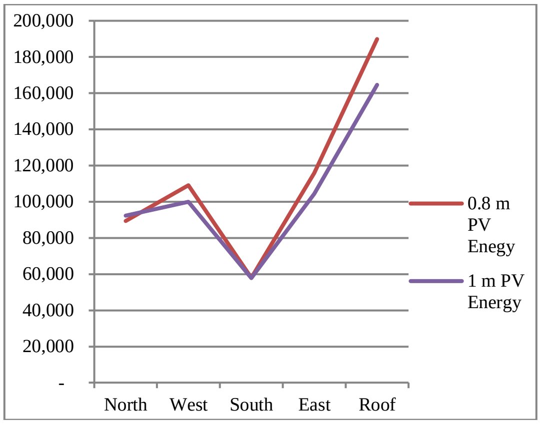


Figure 21. Energy gain

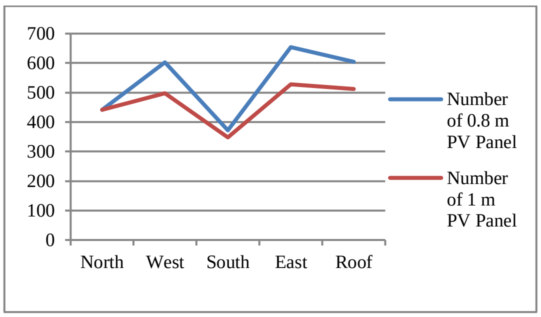


Figure 22. Number of PV panel

Different configurations result in variations in the energy obtained in the hospital building. Figure 22 shows that the optimal energy gain is obtained in the roof configuration with a distance of 0.8 m facing north. It produces the highest energy value among the roof and facade configurations. The optimal energy on the facade is obtained on the east facade with a configuration of 0.8 m. There is a decrease in energy gain with the configuration of 0.8 m on each panel compared to 1 m. This is seen in the decreasing energy gain of each panel in the configurations of 0.8 m.

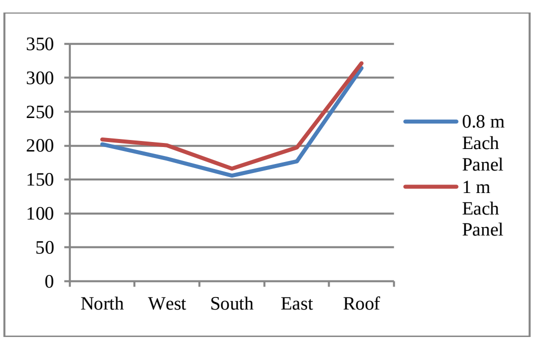


Figure 23. Energy gain on each panel

The optimal energy of each PV panel in the facade and roof is obtained in the configurations facing north with a distance of 1 m. This is in line with Freitas et al. (2020) modeling and assessing BIPV envelopes using parametric Rhinoceros plugins Grasshopper and Ladybug. The study found that the building's highest radiation gain is north. The results support Anantama and Hariyadi (2021), which showed that the northern orientation produces the highest radiation and constant average radiation exposure.

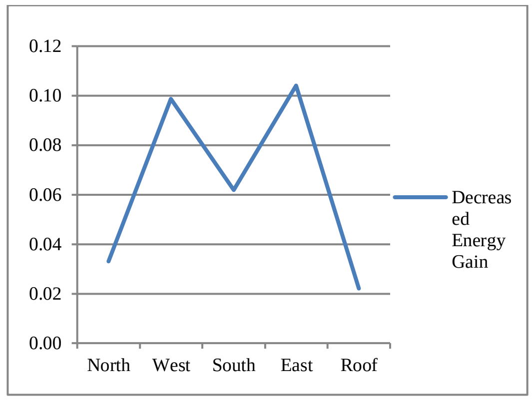


Figure 24. Decreased energy gain

In the configuration of the facade in the north, west, south, east, and roof, the decrease in energy gain is 0.03%, 0.1%, 0.06%, 0.1%, and 0.02%, respectively. The decrease in energy gain is caused by shadowing from other PV panels. The closer the panels are, the more the shadowing effect is produced, reducing energy gain. The results support Kumar, Samykano, and Karthick (2021) discussing Energy loss analysis of a large-scale BIPV system for university buildings in tropical weather conditions: A partial and cumulative performance ratio approach. The study found that the decrease in energy gain was caused by shadowing from the BIPV array, resulting in 0.27-3.56% energy reduction.

Based on the results of the PV simulation in the Trauma Center building of RSUP NTB above, the value of the Break Event Point was calculated based on table 7. It is adjusted to the building's annual energy needs of 977,021 Kwh and PV investment of Rp. 4,100,000,0 per panel. The BEP value on the facade was compared with the value on the roof.

Table 7. BEP calculation

Profit	Pv 0.8	Nmbr Pv	Energy Pv	E wth Pv	Cst wth Pv	Invest	BEP
128,810,519	Fsd Utr	442	89,204	887,817	1,282,007,503	1,814,896,200.0	14.1
157,308,684	Fsd Brt	603	108,940	868,081	1,253,509,338	2,475,978,300.0	15.7
83,652,190	Fsd Sltn	372	57,931	919,090	1,327,165,831	1,527,469,200.0	18.3
167,163,590	Fsd Tmr	654	115,764	861,257	1,243,654,431	2,685,389,400.0	16.1
274,163,274	Atap	604	189,864	787,157	1,136,654,748	2,480,084,400.0	9.0
Profit	**Pv 1**	**Nmbr Pv**	**Energy Pv**	**E Wth Pv**	**Cst Wth Pv**	**Invest**	**BEP**
133,207,101	Fsd Utr	442	92,249	884,772	1,277,610,920	1,814,896,200	13.6
144,134,179	Fsd Brt	498	99,816	877,205	1,266,683,843	2,044,837,800	14.2
83,425,963	Fsd Sltn	348	57,774	919,247	1,327,392,058	1,428,922,800	17.1
150,634,189	Fsd Tmr	528	104,317	872,703	1,260,183,832	2,168,020,800	14.4
237,649,298	Atap	512	164,577	812,444	1,173,168,723	2,102,323,200	8.8

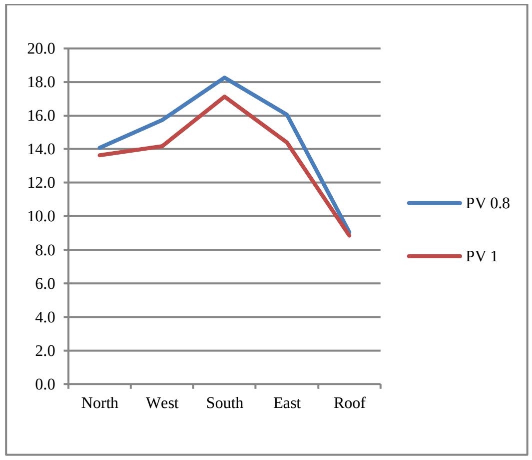


Figure 25. Break Event Point chart

A PV system on the roof is more profitable when applied with a Break Event Point value of 8.8 and 9 years with distances of 1 m and 0.8 m, respectively. The results showed that laying PV on the roof with a distance of 1 m is the optimal value based on the BEP calculation from the configuration in the RSUP building. This BEP value is in line with S. G. and Rangkuti (2016) on the Planning of Solar Power Plants on the Roof of the Harry Hartanto Building, Trisakti University. The study found that the Pay Back Period value for installing solar panels on the roof of the Harry Hartanto building, Trisakti University, shows 8 years 5 months. The obtained BEP number varies slightly depending on the radiation level, slope, and shading effect. The results also support Brito et al. (2017) on the importance of facades for the solar PV potential of a Mediterranean city using LiDAR data. The study showed that installing PV on the roof could return capital under 10 years, while mixed configurations on the roof and facade could exceed 15 years. Moreover, Pramudita, Aprillia, and Ramdhani (2021) conducted the PLTS on Grid Economic Analysis for 2200 VA Houses. The study found that the PLTS on a grid system in meticulous homes was superior to comparison houses, with results in the BEP Simple Payback and Discounted Payback of 7.60 and 8.73 years, respectively.

Applying PV in the facade is relatively more expensive than laying on the roof, as seen from the longer BEP on the facade. This is in line with Middelhauve et al. (2021) on the Potential of Photovoltaic Panels in Building Envelopes for Decentralized District Energy Systems. The study found that PV panel placement is prioritized in the roof area due to the higher energy generation potential than the façade. Also, laying on the roof is cheaper and produces more energy than the facade.

Laying PV on the roof would be more profitable in 20 years with a higher efficiency value than on the facade, as described in table 8:

Table 8. Efficiency calculation

PV 0.8	E Wth PV	Cost wthout PV 20 Yrs	Cost Wth PV	TOTAL A	TOTAL B	Efficiency
Fsd Utr	1,624,342	28,216,360,427	25,870,810,247	28,216,360,427	27,703,855,409	1.82
Fsd Brt	1,983,713	28,216,360,427	25,351,878,432	28,216,360,427	27,852,616,515	1.29
Fsd Sltn	1,054,881	28,216,360,427	26,693,112,077	28,216,360,427	28,235,855,969	-0.07
Fsd Tmr	2,107,987	28,216,360,427	25,172,427,417	28,216,360,427	27,884,670,7 11	1.18
Atap	3,457,287	28,216,360,427	23,224,037,415	28,216,360,427	25,728,922,659	8.82
PV 1	**E Wth PV**	**Cost Wthout PV 20 Yrs**	**Cost Wth PV**	**TOTAL A**	**TOTAL B**	**Efficiency**
Fsd Utr	1,679,785	28,216,360,427	25,790,751,531	28,216,360,427	27,623,796,693	2.10
Fsd Brt	1,817,579	28,216,360,427	25,591,777,028	28,216,360,427	27,657,063,206	1.98
Fsd Sltn	1,052,028	28,216,360,427	26,697,231,511	28,216,360,427	28,140,443,539	0.27
Fsd Tmr	1,899,546	28,216,360,427	25,473,416,342	28,216,360,427	27,663,117,350	1.96
Atap	2,996,834	28,216,360,427	23,888,931,584	28,216,360,427	26,012,278,016	7.81

Energy production for 20 years is assumed to reduce cell efficiency by 1% yearly. The value of A is the sum of the price of electricity needs without a photovoltaic system. In contrast, B is the price of electrical energy with PV, total investment, and maintenance assumed to be 1% of the investment.

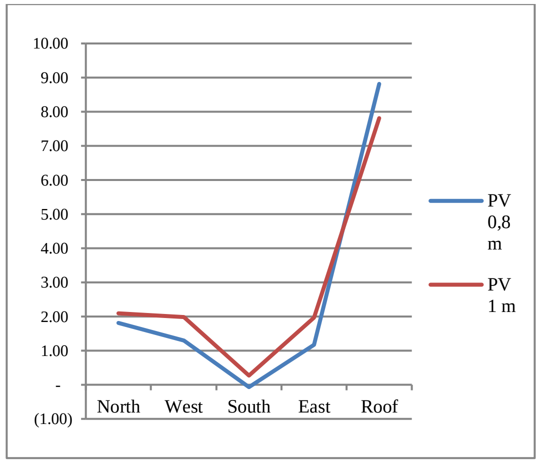


Figure 26. PV efficiency

The efficiency of the PV system at a distance of 0.8 m on the facade and roof is 4.21% and 8.82%, while the configuration at 1 m is 6.31% and 7.81% efficient, respectively. Therefore, the efficiency of the PV configuration on the roof is more effective than on the facade. The configuration on the roof with a distance of 0.8 m facing north is the optimal value in the RSUP building with the highest efficiency value. This is in line with Freitas et al. (2020) discussing modeling and assessing BIPV envelopes using parametric Rhinoceros plugins Grasshopper and Ladybug. The study found that the surface used for BIPV applications on buildings in the middle zone of Brasilia showed a pronounced shadow effect by the surrounding buildings, fairly high vegetation, and shading and panels due to the building's geometry. The BIPV system on the facade surface only reaches between 2.66% and 10.56%. According to Abdullahi et al. (2021) in A review of building-integrated photovoltaics: A case study of tropical climatic regions, most studies focused on new designs to improve efficiency. The study found that BIPV applications on facades and roofs achieve efficiency values between 5-18%.

Conclusion

The highest energy gain value is found in the roof configuration with a distance of 0.8 m facing north. Similarly, the highest energy on the facade is obtained in the eastern configuration with a distance of 0.8 m and proportional to the number of panels used. The optimal energy is obtained on the facade and roof configuration with a distance of 1 m facing north. This shows that tightly placed PV panels are less effective in generating energy.

Laying PV on the roof and facade with a distance of 1 m facing north is the optimal value based on BEP calculations. The north side of the facade with a distance of 1 m is the most optimal configuration with an efficiency rate of 2.1%. Similarly, the northern roof configuration with a distance of 0.8 m facing north is the most optimal, with an efficiency of 8.82%.

Laying PV on the roof would be more effective within 20 years than on the facade. This is because the efficiency value on the roof is quite high compared to the facade. The PV system with a distance of 0.8 m on the facade and roof has a total efficiency of 4.21% and 8.82%, respectively. The configuration with a distance of 1 m produces an efficiency of 6.31% on the facade and 7.81% on the roof. This means that the efficiency of the PV configuration on the roof is more effective than on the facade. Therefore, the Trauma Center Hospital should use the optimal value on the roof with a configuration of 0.8 m facing north with an efficiency value of 8.82%. Another alternative is using a configuration of 1 m on the facade with an efficiency of 6.31%.

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Author(s) contribution

Lalu Muhamad Gantara Ranusman contribute to the research concepts preparation and literature reviews, data analysis, of article drafts preparation and validation.

Agus Hariyadi contributed to the research concepts preparation, methodologies, investigations, data analysis, visualization, articles drafting and revisions.