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Study of Orientation on The Effectiveness of Photovoltaic Shading Installation in The Ulil Albab Mosque, Yogyakarta

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Abstract

A mosque is a place of worship oriented towards the Qibla, which for the Yogyakarta area is in the northwest direction, or 294.7°. The Qibla will affect the orientation and possibly the shape of the building. The northwest direction of buildings in Yogyakarta has a relatively high solar factor value. The orientation of the building and the dominant shape of the building towards the Qibla cannot be avoided by architects because of the rule of shafts during congregational prayers. This research is expected to find the practical orientation and layout of photovoltaic installations that function as shading, which can reduce solar heat radiation. It is hoped that the distinctive orientation of the mosque will have great potential to produce maximum renewable energy by installing solar/photovoltaic panels. The orientation has excellent potential for a mosque building to produce maximum renewable energy by installing photovoltaic (PV) panels in addition to the roof. This research aims to clearly and measurably determine the potential for renewable energy in an existing mosque, namely the Ulil Albab Mosque, Yogyakarta. The method used in this research is to carry out simulations on all facade orientations using FormIt software to find the most effective potential facades for installing PV. This research shows the most significant potential for installing photovoltaics without disturbing the performance of other buildings and getting optimal energy on the side west by producing 86,76 kWh/year.

Keywords: *orientation; performance; PV; solar radiation*

Introduction

Indonesia is in a tropical climate with almost the same length of day and night, about 12 hours. Sunlight also carries the heat that the heat can feel through radiation. That energy has always been given to us because of Indonesia's location in the tropics. The light of this sun touches all that is on the Earth's surface, including its buildings. Building surfaces will often get sunlight depending on the building's orientation. Choosing the correct building orientation is a way to get a good building position to catch or avoid exposure to sunlight. The mosque is a place of worship for Muslims, usually for their religious activities. The mosque is categorized as a temporary residential building with a specific schedule of operations occupied five times a day for 30 to 60 minutes each [Budaiwi, I.2013]. These

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times are dawn, day, evening, sunset, and night. We should also consider the jumbo prayer on Friday noon, which lasts about an hour, and during Ramadhan, when the mosque is in full use for 24 hours. The energy of the building field. The position of the building against the sun is so important that it needs to be calculated and considered. The consideration relates to the magnitude of the sun's radiation falling onto the building's surface, namely the roof elements and the outer surface of the building, such as walls, glass, and facades, and because these elements were the first to receive direct sunlight.

The efficiency of the design is essential; besides, it is how to make the mosque have renewable energy from the sun on the surface. Energy conservation using the sun by installing photovoltaics on buildings has been found in Indonesia. Various types of buildings, such as institutional buildings, offices, housing, factories, worship places, and others, have used solar panels/photovoltaics as a reserve and primary energy source. Back again because of the abundant potential that comes from the source of sunlight. Such a phenomenon is a good thing because it includes energy-saving efforts. One of the indicators of GBCI, when the building is categorized as Green, is that it can produce at least 0,5% of the total energy needs per year (GBCI 2018). In the long term, using energy from sunlight is one of the environmentally friendly energy sources as it does not generate pollution or other garbage residues, so it becomes essential that the Ulil Albab Mosque becomes the place of this research because the mosque always has a westward orientation that is likely to have the potential to use solar panels/photovoltaic as its reserve energy source. Besides, since the mosque was completed in 2001 and is still functioning now, there is a need for improvements in the performance of the building, one of which is the conservation of solar energy.

he orientation and mass shape of the building also need to be assessed for the effectiveness of capturing sunlight for solar/photovoltaic panels. The study aims to see the influence of the shape and mass orientation of buildings faced by sun exposure received by the module and to find the optimal configuration of the photovoltaic installation to generate renewable energy on the building enclosure. Ulil Albab Mosque, Islamic University of Indonesia, is a case of design because this mosque has a circular facade representing eight directions of cardinal points.

Literature Review

Building Orientation and Solar Radiation

The direction of a structure affects how much solar radiation it receives, which significantly impacts how energy-efficient it is. A building oriented east-west is most suited for solar heat gain since it can collect heat as early in the day as feasible and maintain it throughout the day (Li & Liu, 2018) (Azami & Sevinç, 2021). In Yogyakarta, a building's principal orientation should ideally avoid the longest side facing west and east, thereby minimizing solar radiation. Houses inclined eastward will benefit from the morning sun, while those directed westward will receive the late afternoon sun. (Peres Suzano E Silva & Flora Calili, 2021). Furthermore, precise orientation is crucial to passive solar design since the sun's relative position affects building heat gain. The building's east-west orientation also minimizes glare from the rising or setting sun, enabling consistent daylight harvesting and reducing glare along the building's long faces (Lechner, 2015). Thus, optimizing solar radiation and improving energy efficiency require optimal building orientation (Ibraheem et al., 2017).

The orientation of a building has a significant impact on energy efficiency since it can lessen the need for mechanical systems by utilizing natural resources like wind and sunshine for lighting, heating, and cooling. Reducing energy consumption can be achieved by optimizing building orientation. An east-west direction, for example, facilitates the accumulation of heat throughout the day, whereas a south-facing orientation benefits from more direct sunshine, which lowers the requirement for artificial lighting and naturally warms the space during the winter (Saadon et al., 2015) (Singh et al., 2022). A well-oriented building can also reduce wind and sun exposure, which lessens the need for mechanical heating and cooling systems (Peres Suzano E Silva & Flora Calili, 2021). Consequently, strategic building orientation is one of the most critical steps in creating energy-efficient buildings. Many factors must be considered during the architectural design process, including the local temperature, solar orientation, immediate surroundings, user demands, and usage demand. Every design, including structural, electrical, hydro-sanitary, and architectural, needs to work together. However, modern design elements are emerging due to the need to meet the 2030 agenda's sustainability goals and the development of novel technologies (De Masi et al., 2021). One such example is the use of solar energy to produce energy near the point of consumption. Consequently, using PV to generate electricity must be one more requirement and be included in the list of promises that the project will fulfil. From an aesthetic or energy perspective, BAPV and BIPV systems can profit from a well-designed system. Urban systems frequently face issues including partial shading, non-optimal tilt, and azimuthal variations; as a result, it is essential to understand how each design decision will affect the system's overall performance.

Table1. Solar Radiation factor value

Orientation	Solar radiation factor value
North	130
Northeast	113
East	112
Southeast	97
South	97
Southwest	176
West	243
Northwest	211

Source: GBCI, 2018

Photovoltaic and Solar Radiation

Using semiconductor materials that absorb photons, or solar energy particles, and release electrons to create an electric current, PV systems use solar radiation to create electricity. (Hariharasudhan et al., 2022). Depending on the kind of semiconductor material used, the efficiency of PV cells varies; commercial PV panels have an efficiency of about 15%, while cutting-edge modules have an efficiency of about 25% (Singh et al., 2022). Sunlight, or solar radiation, is an essential component of photovoltaic systems. Since sunlight is everywhere on Earth for a portion of the year, solar radiation is a plentiful supply for photovoltaic systems (Singh & Chaudhary, 2022). Watts per square meter (W/m2) or the total radiation on a horizontal surface are two ways to quantify the solar resource. The two forms of solar radiation that can affect photovoltaic systems are direct beam radiation and diffuse radiation, which is absorbed and scattered by air molecules, water vapour, clouds, dust, pollutants, forest fires, and volcanoes. Individual PV cells are joined to create bigger units known as modules or panels in photovoltaic systems, which are modular (Hariharasudhan et al., 2022). As part of a comprehensive PV system, these modules can be joined to form arrays, and one or more arrays can be connected to the electrical grid (Zhan et al., 2024). The design of modular PV systems can be constructed to satisfy a range of electric power requirements, from modest to enormous sizes (J. Liu et al., 2023) (R. Liu et al., 2024).

In tropical climates, photovoltaic (PV) systems can produce energy by utilizing semiconductor materials to convert solar radiation into electrical current. However, PV modules may need help because of the high humidity and temperatures in tropical areas, which may reduce their efficiency and longevity (4). Despite these obstacles, tropical locations exhibit some of the world's highest solar radiation levels, rendering solar energy a feasible alternative in certain regions (Xu et al., 2022). Solar radiation and PV module temperature (Zhan et al., 2024) are two elements that affect the PV systems' efficiency in tropical areas. Consequently, even though PV systems can be utilized in tropical climates, appropriate maintenance of the PV modules and thorough assessment of the local climate is necessary for maximum performance and durability (Singh et al., 2022)

In tropical climate regions, there are numerous instances of effective photovoltaic installations. For example, because tropical countries have more hours of sunlight, particularly in the summer, utility-scale photovoltaic power facilities are erected there. Furthermore, significant insolation rates are frequently experienced in tropical areas, making them an ideal location for solar power plants. A study that examined 27 solar power plants situated in various temperature zones around the nation discovered that arid regions, like the Yazd region, have more solar power plant-suitable locations than provinces with wet climates (Singh et al., 2022). Moreover, light exposure is abundant in arid and semi-arid regions, leading to the widespread use of photovoltaic modules in these climates. The endurance and efficiency of solar panels in tropical areas are improving due to continued study and technological innovation despite the constraints provided by high temperatures, high humidity, and frequent dust storms (Xu et al., 2022).

Indonesia, with enormous solar energy potential, has effectively adopted PV technology. Solar panels can be installed in many places in Indonesia, such as on rooftops, inland reservoirs, mining wastelands, and in conjunction with agriculture. The nation's energy ministry has shortened permission wait times and raised the rooftop on-grid solar capacity export allowance. By the end of the year, the share of solar energy in power generated on Lombok, one of the Nusa Tenggara Islands in southeast Indonesia, had climbed to 2.8 percent (IMF, 2022). By 2025, 35 percent of the province's electricity will come from renewable sources, primarily solar power, according to Nusa Tenggara's regional government. The decreased cost of solar PV power obtained, with the cost of PPA solar PV reducing by almost 78% from US$0.25/kWh to US$0.056/kWh between 2015 and 2021, indicates Indonesia's advancement in solar energy. One sustainable energy option that is still promoted in Indonesia4 is solar energy. Large-scale solar PV projects will help Indonesia meet the Paris Agreement's carbon-neutral goal by 2050 (Country Profile, 2022).

Photovoltaic and Shading Devices

Integrating photovoltaic technology into building envelopes, such as facades and roofs, presents an opportunity for adaptive energy and comfort management and decentralized district energy systems. Studies have indicated that PV panels can be used on building envelopes to generate local solar energy. Local solar can yield substantial electricity gains and energy savings, especially in desert and temperate areas (1-2). Building-integrated photovoltaics, or BIPV, are often used in constructing new buildings. BIPV entails the integration of PV modules into the building envelope, acting as both a construction material and a power generator (Azami & Sevinç, 2021). BIPV materials, which take the role of conventional building materials, provide various design options and can improve solar materials' transparency and energy efficiency. (De Masi et al., 2021). As a result, a viable strategy for energy generation and management in the built environment is integrating PV technology into building envelopes. In many nations, it is possible for structures to generate energy. However, important choices must be made during the design phase if you want the optimum aesthetics and energy efficiency from the PV architectural integration. These tools can be used throughout the design phase of PV projects to help decision-makers assess how best to use solar irradiation and how shade affects performance under various orientation and inclination situations. Each tool was introduced, and an explanation of how to utilize it to help and direct the architectural project's defining process was provided. A better understanding of decision-making was also made possible by the spotlight on each tool's crucial decision-making points (Zomer et al., 2023).

Photovoltaic, Building Orientation and Renewable Energy

In many nations, structures can generate energy. However, important choices must be made during the design phase if the architect wants the optimum aesthetics and energy efficiency from the PV architectural integration. Solar calculators and shading masks are tools that architects can use to assess the influence of shading and solar irradiation in various orientation and inclination situations while making decisions during the PV design process. Determining a building's and a site's solar access is the first stage in the passive solar design process. The shading mask will assist the architect in devising tactics to regulate the amount of daylight and heat gain. Diagrams of shading masks are handy tools for figuring out solar access (Saranti et al., 2015).

In addition to increasing energy efficiency, buildings can produce clean, renewable energy. The capacity of photovoltaic solar energy to adapt to buildings and the urban environment makes it stand out among the other sources. In Brazil, 90% of photovoltaic generators are situated on rooftops and slabs of residential and commercial buildings, accounting for 99% of distributed generation (Scognamiglio & Røstvik, 2013).

Aware of how their design choices affect energy consumption, some architects and engineers have begun to design more energy-efficient buildings. These buildings may use active surfaces, like photovoltaic modules, for energy generation or passive design techniques (Azami & Sevinç, 2021) (J. Liu et al., 2023). This method necessitates the aptitude and understanding to use the energy requirements of buildings as inputs for design ideas. The implementation of these tactics results in Zero Energy Buildings (ZEBs) (De Masi et al., 2021).

Unlike traditional energy sources, solar PV is visible. For the first time in architectural history, energy can have a "form" (i.e., a shape, colour, or feature) that is designed by architects (Scognamiglio & Røstvik, 2013) (Marei et al., 2024). The feasibility of BIPV applications was investigated by proposing a comprehensive mapping tool that included a quantitative visual impact assessment and traditional energy yield projections (Fu et al., 2024). The comprehensive mapping tool BIPV requires strategic planning to maximize the production of renewable energies while maintaining the aesthetic quality of the urban landscape, particularly in densely populated urban environments. In order to get the most significant outcomes in terms of integration into the architecture and energy performance of the photovoltaic system, a BIPV project necessitates several considerations during the design phase.

The irradiation and shading study is an essential part of the design process for PV systems incorporated into buildings in urban or rural regions. Architects and engineers may contribute to a more responsible and environmentally friendly built environment by designing buildings that are aesthetically beautiful but also sustainable and energy-efficient, all achieved through practical design techniques (Ibraheem et al., 2017).

Methodology

This research uses quantitative methods by modelling objects and simulations with computer software. The use of simulation methods is chosen to avoid the difficulty of direct research on real objects. In this study, the finished building was used. Ulil Albab Mosque, Islamic University of Indonesia, is a case of design because this mosque has a circular facade representing eight directions of cardinal points.

The simulation method is used in experiments using computer software to produce predictions without conducting experiments directly. This method uses a replica (model) in a real-world context, which is controlled (manipulated) to study the interaction between the model's manipulated factors. In this case, the interaction between the building model and the simulated object location weather data.

The completed 3D model is then simulated: http://andrewmarsh.com/software/shadingbox-web/ to obtain results in the form of the date and time the PV module will receive much direct sunlight. The 3D model was simulated to determine the exposure to solar radiation received by each Ulil Albab Mosque's outer surface. The simulation uses the FormIt application provided by AutoDesk. The 3D model is simulated each month and cumulated for one year with units of kWh/m².

Describes all of the research procedures that were employed; it serves as a contrast or story for several case study pieces or lengthy research projects. Experimentation can also be done as research. All the procedures in the research technique should be followed until the study's objectives are satisfied.

The independent variable used in research is solar radiation. Fixed variables are space area and building orientation.

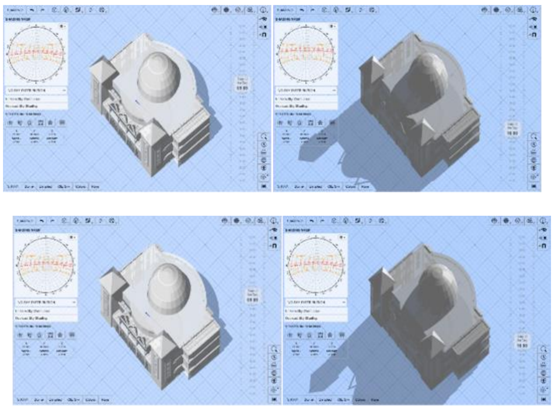
Result and Discussion

Shading Simulation on Facade

The shading simulation in the north facade was carried out in April and October because these are the effective beginning and end of the month for the photovoltaic module to receive solar radiation.

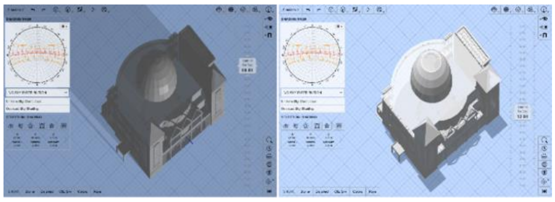
In April and October, it was found that the effective hours were 7 hours, starting at 9.00 am – 4.00 pm.

Figure 1. Shading simulation in north facade
Source: Researchers, 2023



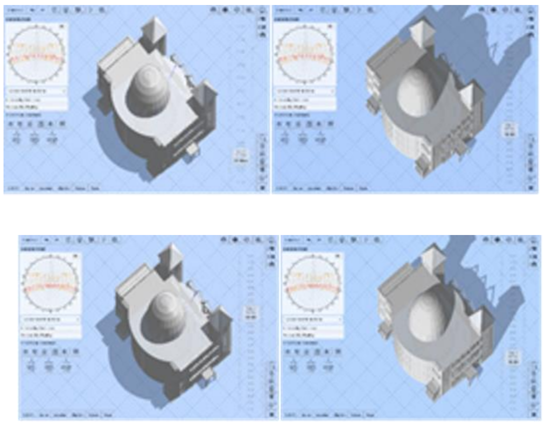
The shading simulation on the east facade was carried out in March, even though the simulation on the east side facade could be carried out in any month. Based on the amount of radiation that falls on the surface of the photovoltaic modules on the east facade, it can be effective throughout the year. The practical hours for obtaining solar radiation are 7, namely 06.00 am – 1.00 pm.

Figure 2. Shading simulation in east facade
Source: Researchers, 2023



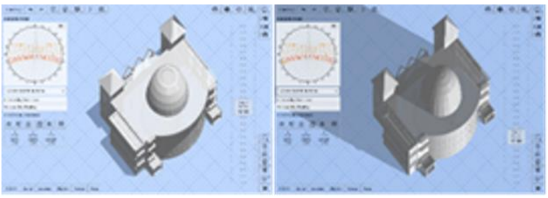
The shading simulation in the south facade was carried out in November and February because these are the beginning and the end of the month, which effectively receive solar radiation on the photovoltaic module. It was found that the effective hours in November and February were 7 hours, namely 09.00 am – 4.00 pm.

Figure 3. Shading simulation in south facade
Source: Researchers, 2023



The shading simulation in the west facade was carried out in March, although the simulation on the east side facade could have been carried out in any month. Based on the amount of radiation that falls on the surface of the photovoltaic module on the east facade, it can be effective throughout the year. The result is an effective clock length of 4.5 hours, namely at 12.30 pm– 5.00 pm.

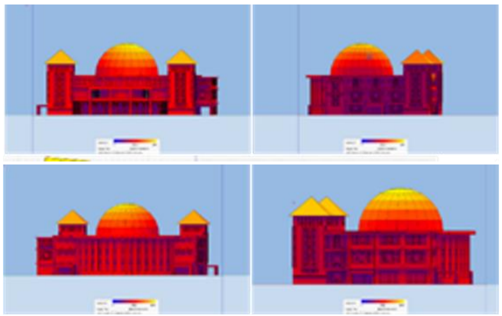
Figure 4. Shading simulation in west facade
Source: Researchers, 2023

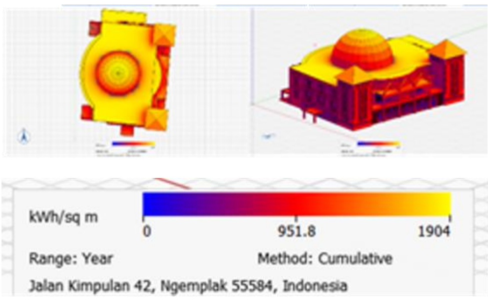


Simulation Of Exposure to Solar Radiation

The Ulil Albab Mosque building gets the most exposure to solar radiation throughout the year on its roof elements. The roof gets the most exposure to solar radiation, reaching 1904 kWh/m². Meanwhile, the facade elements of the building do not receive as much radiation exposure as the roof elements. On the facade of the building, it is around 951.8 kWh/m². This can be seen in the simulation visualization image in Figure 5.

Figure 5. Soar radiation in roof and facade
Source: Researchers, 2023



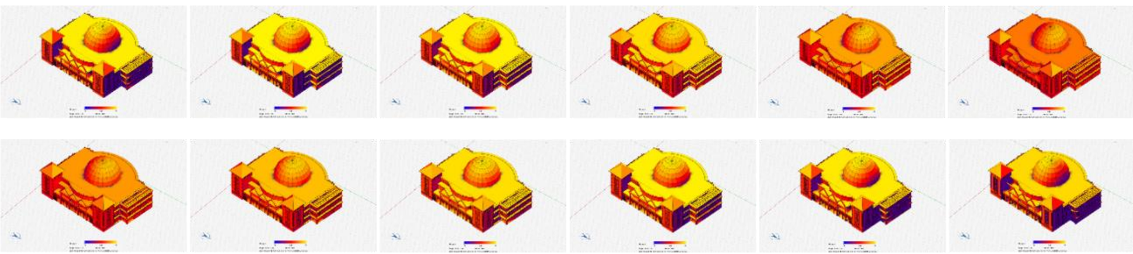


Direct sun exposure to the building's roof makes it an excellent and suitable place to place PV modules (Zhan et al., 2024). The roof is in the highest position with a flat surface, which means it will be more perpendicular to sunlight. Likewise, rectangular pyramid roofs also receive a lot of direct solar radiation energy. A lower roof will receive less direct solar radiation.

Photovoltaic Installation on The North Facade

The simulation was carried out on the northern facade by placing photovoltaic panel modules on the walls and shading the windows so that the photovoltaic panel modules did not cover the window openings with a 15° module tilt that is installed as an overhang (Saranti et al., 2015). Towns nearer the equator have a smaller tilt angle because of the direct correlation between the distance from the sun to the cities and the amount of light they receive. The angle is 15 degrees in the vicinity of Khatulistiwa, Indonesia. Madrid is closer to the equator than the other four cities, with a tilt angle of almost 27°. Also, this value rises to Berlin's highest point, around 41°, as the distance between cities and the equator increases (Baghoolizadeh et al., 2022).

Figure 6: Simulation of solar radiation of North facade photovoltaic module
Source: Researchers, 2023

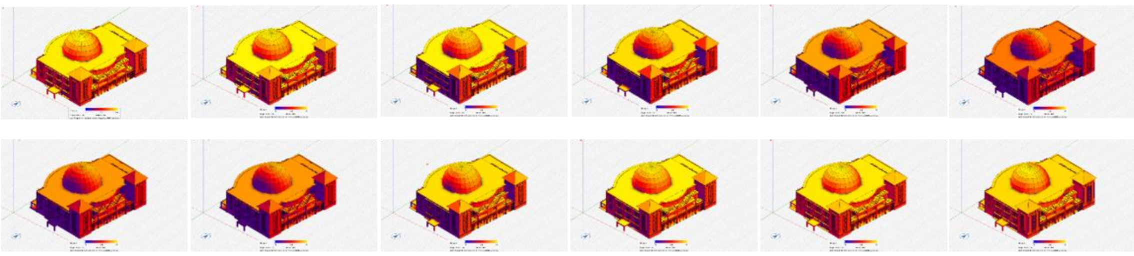


The result is that there are eight effective months, namely March – October, to capture solar radiation energy. The most effective months are August and September, with the acquisition of solar radiation energy hitting the surface of the photovoltaic module panels reaching a maximum point, namely 509,19 Kwh/m². However, installing photovoltaic modules on the northern facade is not entirely adequate because there are times when the photovoltaic panel modules do not receive solar radiation energy. This is related to the sun's position, which constantly changes monthly. Installation of (Azami & Sevinç, 2021).

Photovoltaics on The East Facade

The photovoltaic panel module simulation on the east side of the building can only be used to place the photovoltaic panel module on the flat roof. Because the sides facing east have huge openings, it is impossible to place photovoltaic panel modules in the opening elements. The tilt of the photovoltaic module is 15°. The simulation results show that on the eastern side, there are no significant changes each month. The simulation results are less significant than those for the north-side facade. The shadow covering the photovoltaic surface that occurs each month is much less than in the simulation of the north side facade. However, it was still found that there were months less effective in capturing solar radiation energy, namely May-August (4 months). Effective acquisition of solar radiation energy occurs in September – April, with the acquisition of solar radiation energy falling on the surface of the photovoltaic module amounting to 438,65 kWh/m².

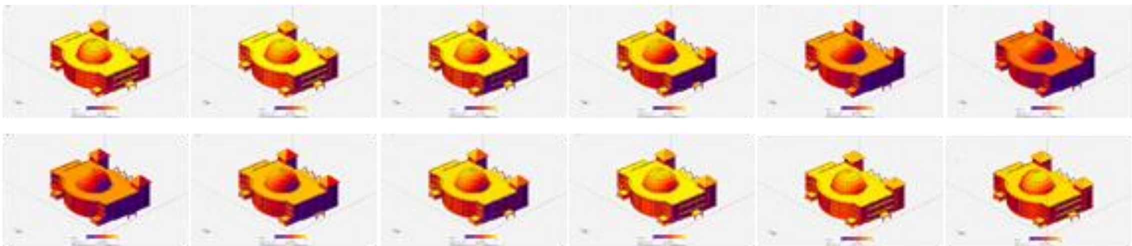
Figure 7: Simulation of solar radiation of East facade photovoltaic module
Source: Researchers, 2023



Installation Of Photovoltaics on The South Facade

The photovoltaic panel module is placed on the top of the shade. Photovoltaic panel modules cannot be installed on facade walls because there are wide openings on almost the entire wall surface. The 15° module slope is installed as an overhang. The result is that there are five effective months for photovoltaic panel modules to receive solar radiation, namely October – February. The highest amount of solar radiation was obtained in December, reaching a maximum radiation of 379,93 kWh/m². However, installing photovoltaic modules on the south side facade has a relatively long period of 7 months, namely March – September. This happens because Indonesia's geographical location has the sun's position, which tends to be more to the north, so shadowing on the south side is more dominant.

Figure 8. Simulation of solar radiation of South façade photovoltaic module
Source: Researchers, 2023



Installation Of Photovoltaics on The West Facade.

Simulating the photovoltaic panel module on the west side, place the photovoltaic panel module at the top of the opening shade. The number of photovoltaic panel modules that can be installed is the smallest compared to the other sides of the building facade. The slope of the module is 15°, which is installed as an overhang. The result is that solar radiation falling on the surface of the photovoltaic panel module is almost the same as the simulation results on the east facade. Eight effective months receive much solar radiation on the surface of the photovoltaic module, namely September – April, with a maximum radiation gain of 951,8 kWh/m². However, four months are less effective at receiving solar radiation but are also not overshadowed, namely May – August. So, the west side is the most effective because it has the slightest shadow on the photovoltaic panel module.

Figure 9. Simulation of solar radiation of West façade photovoltaic module
Source: Researchers, 2023

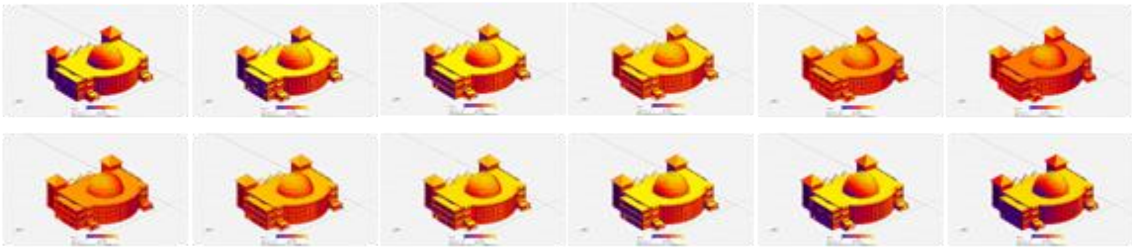


Figure 10. Solar radiation in Building Facade
Source: Researchers, 2023

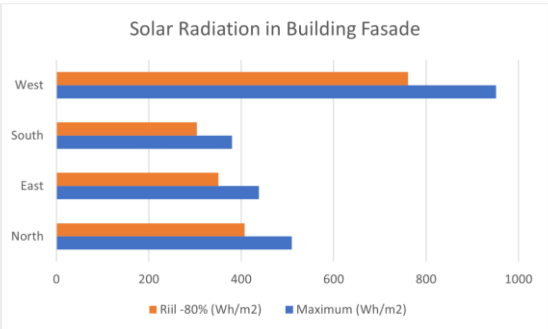
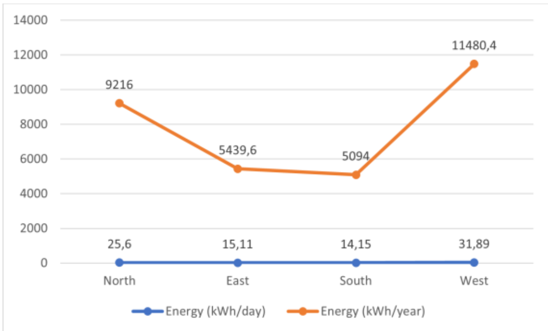


Figure 11. Renewable Energy in Facade
Source: Researchers, 2023



The average solar radiation on the facade can be seen in Figure 8. The most significant solar radiation is on the West facade, and the smallest is on the South. In Indonesia, only 70%-80% will be effective. With the existing building design used in this research, not all orientations can have the same amount of PV installed, which will also affect the energy produced by each orientation (Peres Suzano E Silva & Flora Calili, 2021).

Although few facade areas can be installed on the PV, the western orientation can generate more energy than other orientations. The energy is due to excessive, longer year-round solar radiation, and the facade does not dominate the illuminated elements throughout the year. The orientation and shadows of buildings strongly influence the sun's radiation, affecting the PV performance (Zomer et al., 2023).

Table 2. Facade orientation, space PV unit and energy produce

Orientation	Unit of PV	Energy (kWh/day)
North	54	25,60
East	37	15,11
South	40	14,15
West	36	31,89
Total	167	86,76

Source: Researchers, 2023

The energy that can be produced per year is 31,232.71 kWh/year. With the highest number of PVs on the north side, the energy produced is not as big as on the west side; this is caused by the solar radiation received on the west side being more significant than on the other side.

From the results of research using simulation methods on case buildings, considering design orientation and solar radiation, results were obtained regarding the potential effectiveness of PV installation. The results of this study are as follows:

(1) The orientation of the facade greatly influences the solar radiation that the building envelope will receive and also the duration of shadowing caused by the building design
(2) Installing PV on the facade positioned as horizontal shading without reducing natural lighting does not maximize the number of PVs (Saranti et al., 2015).
(3) Facades with a West orientation have the least amount of PV but can produce more energy because of the more significant solar radiation and longer exposure time.
(4) This research needs to consider daylighting if PV is installed as shading on a transparent facade. Further research is needed to determine the relationship between daylighting and the value of OTTV and its role in energy efficiency (Ibraheem et al., 2017).

Conclusion

The building envelope plays an essential role in thermal, visual, and acoustic building comfort. However, the building cover can also be used as a renewable energy generator by designing a good and careful PV lining. The building's economic costs can be minimized, and its electricity consumption can be decreased by solar shading. In order to fully utilize these solar awnings in the building, there is an upfront expense associated with their installation and upkeep. This research suggests that a good and careful photovoltaic displacement can generate considerable electricity. The building's orientation is very determined for this. In Yogyakarta, the west facade's orientation, along with the case study's design, obtained the most significant radiation exposure. However, the field on the west façade was not so vast. This research has not integrated PV shading as shading with natural illumination accumulation for visual comfort.

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