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Experimental Study of Bifacial Solar Panels with Reflective Surface Variations in Bandung, Indonesia

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***Abstract**. This study aims to evaluate the performance of bifacial photovoltaic (PV) panels under different reflective surface conditions in a tropical urban environment, specifically in Bandung, Indonesia. Bifacial PV systems offer the advantage of capturing solar radiation from both the front and rear sides, with performance significantly influenced by the surface beneath the panels. The experiment involved three surface types: asphalt, untreated paving blocks, and paving blocks coated with white paint. Each panel was installed at a fixed 8° tilt facing north, and data were collected from 09:00 to 15:00 local time. The results indicate that the white-painted surface produced the highest power output, reaching up to 410 Watts, followed by paving blocks at 390 Watts and asphalt at 370 Watts. Although all surfaces received a similar radiation pattern, their differing reflectivity affected the amount of radiation reaching the rear side of the bifacial panels. The white-painted surface, characterized by high reflectance, not only enhanced rear-side radiation capture but also maintained a more stable power output after peak solar hours. These findings highlight the critical role of surface reflectivity in optimizing bifacial PV performance and support the strategic use of surface materials in PV system deployment, particularly in tropical climates. This study contributes valuable empirical data to the growing field of bifacial PV applications and offers practical insights for improving energy yield in real-world tropical settings.*

***Keywords -** Bifacial photovoltaic, reflective surface, solar radiation, energy yield, tropical climate.*

INTRODUCTION

Bifacial photovoltaic (PV) systems offer increased energy yields by capturing solar radiation from both sides, outperforming traditional monofacial systems, especially in high sunlight and reflective environments such as in Indonesia [1] [2]. Capable of increasing energy production by up to 30% under optimal high albedo conditions [1]. With the ability to utilize both diffuse and reflected light, bifacial PV systems are perfect for residential, commercial, and industrial applications [2] [3]. Installation flexibility, such as vertical or east-west orientation, also allows optimization for diverse geographical and climatic conditions, improving energy production and load balancing [1] [4]. Despite higher initial costs, long-term benefits in energy yield and reduced levelized cost of electricity (LCOE) support bifacial PV as a sustainable energy solution, with market share expected to grow significantly [3] [1]. Environmental conditions, orientation, and especially albedo which refers to the reflectivity of the ground surface have a great effect on the performance of bifacial photovoltaic (PV) systems. Studies have shown that bifacial photovoltaic systems can utilize solar radiation on both the front and back sides, with better front-side performance and better back-side performance [5] [3]. In several studies, different reflective surfaces, such as aluminum, white plastic, cement, sand, and grass, have been used to assess the effect of albedo on the performance of bifacial photovoltaics [6][7]. As a result, surfaces with high albedo such as aluminum and white plastic provide the highest bifacial gain, while natural surfaces such as grass produce the lowest gain [6]. Simulation and modeling have also been used to predict the energy output of bifacial PV at various albedo conditions, with analytical models proving more accurate than empirical models [7].

In addition, several studies highlighted the importance of accurate albedo data for system design, especially in complex landscapes [8]. Many studies were conducted outside of Indonesia, so the results are not always directly applicable to Indonesia's tropical and high humidity environment. In addition, many studies use laboratory or simulated data rather than field experimental measurements with real conditions [6] [9] [10]. Research on bifacial photovoltaic (bPV) systems has extensively explored the impact of reflective surfaces and mounting configurations on energy yield, mainly focusing on high albedo surfaces in temperate regions. Studies have shown that bPV systems can achieve significant performance improvements by optimizing backside radiance through various reflective materials and configurations. For example, Garrod et al. highlighted the improved efficiency of bPV systems under scattered radiation conditions in the UK, emphasizing the role of albedo in increasing energy production [5]. Similarly, Lewis et al. quantified the effects of structural shadows and reflections, showing that reflective racks can reduce back radiation shadows by up to 19.2% per year, thereby improving the modeled energy yield[11]. The flexibility of bPV modules allows for diverse mounting orientations, which can further optimize energy yield by enhancing ground reflectance to globally increase bifacial gain [1].

In addition, the application of cool roof coatings has been shown to increase the peak power output of bPV modules by 3.29%, which demonstrates the potential of reflective surfaces to improve performance [12]. However, these studies have largely focused on temperate regions, with limited attention to tropical climates such as Indonesia, where different reflective surfaces may be more common. The potential for improving bifacial gain through optimized mounting systems and selectively increasing soil albedo has been explored, but the specific impact of tropical reflective surfaces remains unexplored [13] [14]. Therefore, while existing research provides valuable insights into the optimization of bPV systems through reflective surfaces, there is a notable gap in understanding the performance implications in tropical regions, which requires further investigation to adapt bPV technology to diverse climatic conditions [15]. The performance of bifacial photovoltaic (PV) systems in tropical conditions, especially with locally sourced reflective materials, remains unexplored, despite promising findings in the existing literature. Research has shown that bifacial PV systems can significantly increase energy yield by utilizing reflective materials, such as white geotextile mats and white gravel, which have been shown to increase energy production by up to 14% compared to monofacial systems [16].

In tropical regions such as southern India, the use of non-biodegradable waste materials as reflectors, such as flexible polyvinyl chloride and thermocol, has shown improved performance ratios, with thermocol achieving 20% higher performance ratios than aluminum foil [17]. However, the impact of commonly available surfaces such as black, chrome, or wood-like materials on the efficiency of bifacial PV in environments with high sun exposure is still poorly studied. In addition, the potential benefits of a fixed, low tilt angle suitable for regions near the equator, such as Indonesia, have not been widely discussed. Research in hot and humid regions, such as Hong Kong, shows that small tilt angles and wide sunshades can optimize energy savings in building-integrated bifacial PV systems [18]. In addition, studies in Colombia have highlighted the financial viability of bifacial systems with higher surface albedo, which show a 4.83% increase in energy generation compared to monofacial systems [19]. This research aims to evaluate the performance of bifacial PV systems in Indonesia by examining the effects of different reflective surface materials, specifically asphalt surfaces and white paint, on energy yield. With a fixed tilt angle of 8 degrees, the study will capture variations in irradiance and energy output, providing empirical data on the suitability of these materials in a tropical environment. Expected contributions include a comprehensive analysis of bifacial PV performance in Indonesia, offering insight into optimal configurations and potentially contributing to local energy strategies utilizing bifacial PV technology.

METHODS

This study is a quantitative field experiment aimed at evaluating the impact of surface albedo on the performance of bifacial photovoltaic (PV) panels. The experimental method was selected because it enables researchers to control environmental variables and directly compare the output performance of bifacial solar systems installed over different surface types: asphalt, white-painted paving blocks, and untreated paving blocks.

The experiments were conducted in an open parking area at Widyatama University in Bandung, West Java, Indonesia. This location was chosen because it reflects the general characteristics of Indonesia's tropical climate, particularly high solar irradiance and humidity. Moreover, the area offered minimal shading and was easily accessible for equipment monitoring.

To ensure the collection of data during peak solar activity, measurements were taken daily between 09:00 and 15:00 Western Indonesian Time (WIB). Three identical bifacial PV panels rated at 500 Wp were used in the experiment. Each panel was tested on a different surface per day, mounted at an 8° tilt facing north—an optimal orientation for the latitude of Bandung.

Table 1. Materials and Specifications

Item	Specification
Bifacial PV Panel	500 Wp
Pyranometer	Range: 0–1800 W/m²
Dummy Load	Resistor 4.2 Ω, 1000 W
Data Logger	Automatic recording every minute
Asphalt	Albedo: 0.05 – 0.10
White Paint Surface	Albedo: 0.60 – 0.90
Paving Block	Moderate Albedo 0.20–0.30

Electric current and voltage data were recorded using a multichannel data logger, while solar irradiance data were captured using a pyranometer. The power output (P) was then calculated using the standard formula:

$$P = V \times I$$

where P is power (Watts), V is voltage (Volts), and I is current (Amps). The efficiency of the bifacial PV system can also be evaluated by comparing the power output against the total irradiance (front + rear).

The setup and execution of the experiments were documented in the following images:

Figure 1. Testing Over Asphalt Surface

In this configuration, the bifacial panel was placed over an asphalt surface with low albedo (0.05–0.10). This test aimed to assess how minimal reflected radiation affects the rear-side contribution of the panel.

Figure 2. Testing Over Paving Block Surface

In this setup, the panel was installed over untreated paving blocks, representing a medium-albedo surface. This served as a comparative baseline between asphalt and painted surfaces.

Figure 3. Testing Over White-Painted Surface

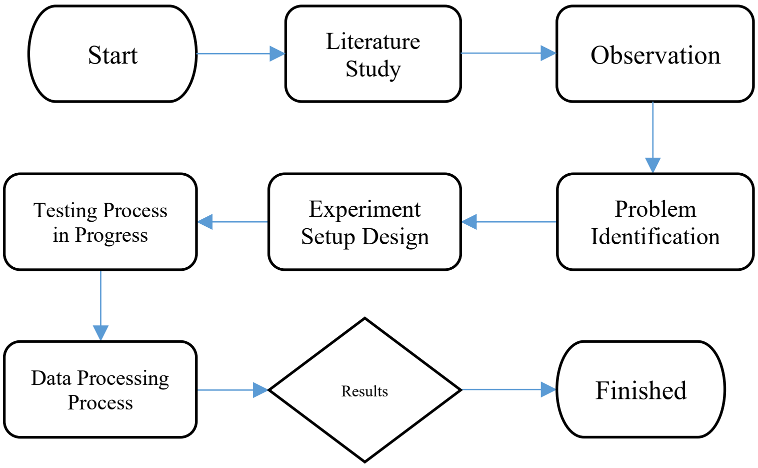

Figure 4. Testing Process

Results and Discussion

This research was conducted on three surfaces: asphalt, paving blocks, and white paint. It took place from 09:00 to 15:00. The main objective of this study is to examine how bifacial photovoltaic (bifacial PV) solar panel systems operate in a tropical urban environment, specifically in the city of Bandung. With a relatively high level of solar radiation every day, this environment is a tropical wet climate.

Solar Radiation on Three Types of Surfaces

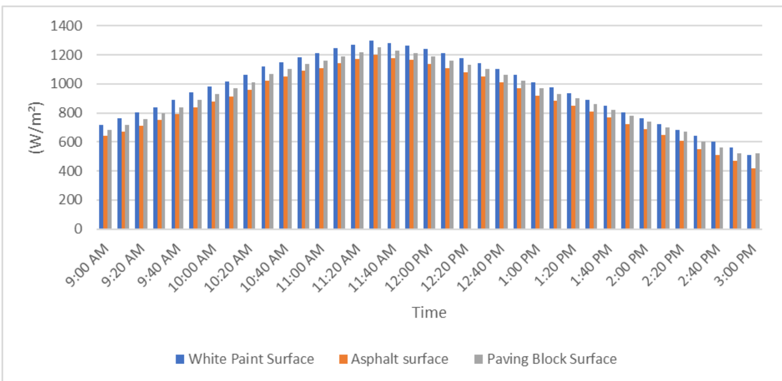

Figure 5. Intensity of solar radiation

Three types of surfaces, white paint, asphalt, and paving blocks, are affected by solar radiation, as shown in the graph above. All three generally have the same pattern, and the radiation intensity peaks around 11:40 to 12:00 with an intensity of almost 1300 W/m2. The white-painted surface appears to receive more radiation. This is due to the reflective nature of its surface, which causes incoming sunlight to be reflected back and spread more evenly around it. In contrast, the asphalt surface absorbs more light than it reflects, so the amount of light that the solar panel can use (especially on the back side) is reduced. The different characteristics of these surfaces clearly affect the amount of electricity generated. The panels perform better because the white-painted surface increases reflection. Followed by asphalt, which reflects the least light, and paving blocks.

Output Power and Solar Radiation on Asphalt Surface

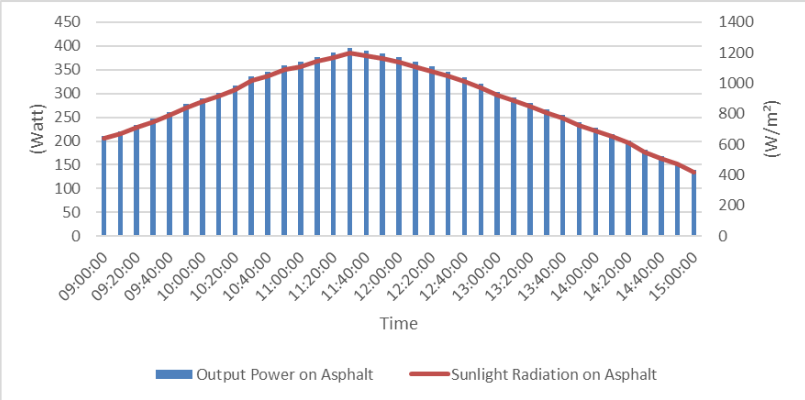

Figure 6. Output Power and Solar Radiation on Asphalt Surface

The graph in Figure 6 shows a pattern of increasing power output on the asphalt surface as solar radiation increases from 09:00 until it peaks around 12:00. The highest power output recorded was 370 Watts, which corresponds with the peak intensity of radiation. After that point, both radiation and power output gradually decrease until 15:00. The asphalt surface responds to radiation consistently, showing a linear relationship between the energy received and the energy emitted, with a strong absorption characteristic towards solar radiation.

Output Power and Solar Radiation on Paving Block

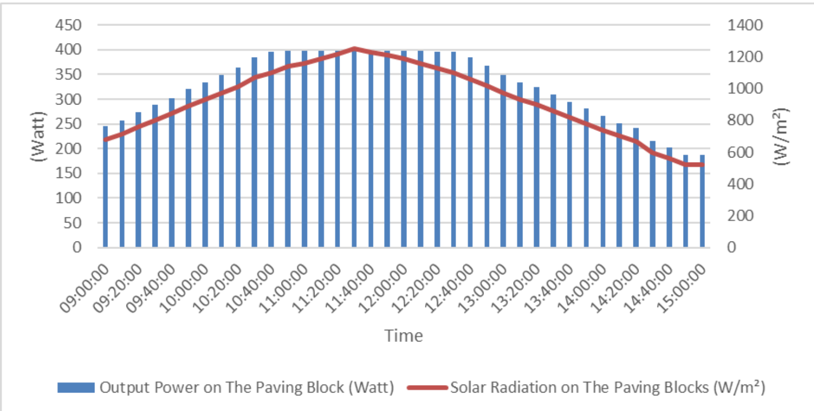

Figure 7. Output Power and Solar Radiation on Paving Block

Graph 7 illustrates that paving blocks also experience an increase in power output in line with the rise in solar radiation intensity. The peak power output recorded was higher than asphalt, at around 390 Watts. Although the surface characteristics of paving blocks are generally not as intense as asphalt in absorbing radiation, this material still manages to provide high and stable power output. After reaching its peak at noon, the power output and radiation intensity gradually decreased in a regular pattern.

Output Power and Solar Radiation on White Paint

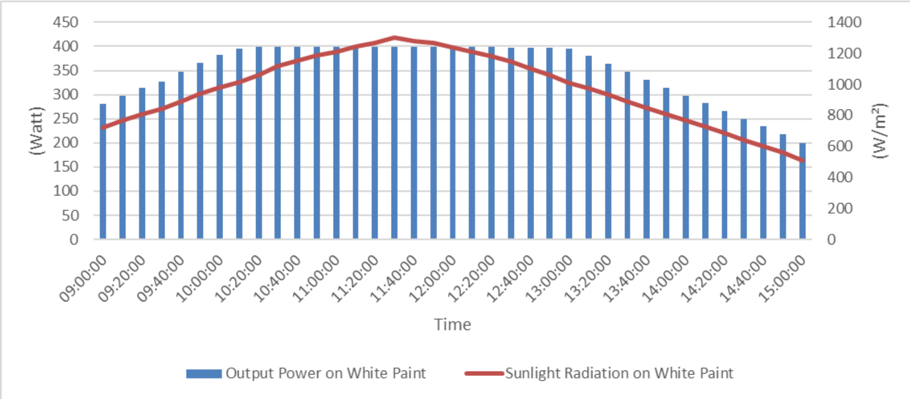

Figure 8. Output Power and Solar Radiation on White Paint

The third graph in Figure 8 shows that the surface with white paint produces the highest power output among the three, reaching a maximum value of around 410 Watts at 12:20 PM. Interestingly, although the radiation received is not much different from the other two surfaces, the output power generated is greater and tends to remain more stable after passing the peak. This indicates the effectiveness of the white paint surface in optimizing the response to solar radiation and maintaining output performance over a longer duration.

CONCLUISON

Based on the research results on the performance of bifacial solar panels on three different types of surfaces in a tropical environment, it was concluded that the surface characteristics have a significant impact on the output power generated. The surface with white paint produced the highest power output, at 410 Watts, followed by the unpainted paving block surface at 390 Watts, and the asphalt surface with the lowest power output at 370 Watts. These results indicate that the greater the surface's ability to reflect solar radiation, the more significant the contribution to the power increase from the rear side of the bifacial panel. These findings support the hypothesis that the use of reflective surfaces can significantly enhance the efficiency of bifacial solar panel systems. With a fixed tilt configuration of 8° and measurements taken between 09:00 and 15:00 WIB, this study provides relevant empirical data for the application of renewable energy technology in tropical regions. In the future, development can be directed towards further exploration of local surface types that are economical and easy to implement, as well as the optimization of system design based on specific environmental variables, so that the results of this research can serve as a foundation for planning and energy policies based on bifacial solar panel technology in Indonesia.

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