



Performance Of Bifacial Solar Panels In Urban Environments

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Abstract: As cities get bigger and people want more clean energy solar power becomes a key answer. This study looks at how well two-sided solar panels work compared to regular one-sided panels using MATLAB computer tests. We found that two-sided panels make a lot more energy because they can catch light from both sides showing, they could be good for city energy plans. Besides the computer tests, we also check how these panels do in real life, like with changing sunlight and shiny surfaces you find in cities. The chance to make more energy could mean less land is needed for solar setups, which matters a lot for cities without much space. Also, two-sided panels look better, which helps when putting clean energy stuff in crowded areas. Our work shows it's important to put money into new solar tech as part of a bigger plan for clean energy dealing with both nature and city planning needs.

Index Terms - bifacial, efficiency , gain factor, monofacial

I. INTRODUCTION

As urban populations continue to grow and global energy demands increase, cities face significant challenges in meeting their energy needs while minimizing environmental impact. Solar power, as a clean and renewable energy source, has emerged as a critical component in addressing these challenges. However, space constraints in densely populated urban areas necessitate more efficient solar technologies that can maximize energy production in limited areas. Bifacial solar panels, which capture sunlight from both the front and rear sides, offer a promising solution to this problem. Unlike traditional monofacial panels, bifacial panels can generate additional energy by harnessing reflected light from surrounding surfaces, such as rooftops, roads, and building facades. This capability enhances their potential for higher energy yields, making them particularly suitable for urban environments.

This study investigates the performance of bifacial solar panels in comparison to conventional monofacial panels using MATLAB simulations. By simulating various real-world conditions, such as different sunlight angles and surface reflectivity, the research aims to evaluate the efficiency gains that bifacial panels can provide in urban settings. The increased energy output from bifacial panels has the potential to reduce the amount of land required for solar installations, a critical consideration for space-constrained cities. In addition to their energy performance, bifacial panels offer aesthetic benefits, making them easier to integrate into urban landscapes where visual impact is a growing concern.

The findings of this research underscore the need for urban planners and policymakers to consider advanced solar technologies like bifacial panels as part of broader sustainable energy strategies. By optimizing energy production in limited urban spaces and contributing to the overall sustainability of cities, bifacial panels can play a key role in meeting future energy demands while reducing reliance on fossil fuels. This paper explores both the simulated and practical applications of bifacial solar panels, highlighting their potential to transform urban energy strategies.

II. EARLY CONCEPTS (1960s – 1970s)

The concept of bifacial solar panels can be traced back to the 1960s and 70s. Scientists recognized early on that traditional monofacial solar panels only captured sunlight from one side, meaning a significant portion of potential energy was being lost. Russian scientist Dr. Vladimir Lushchikov is often credited with developing the first bifacial solar cell in the 1970s. These early bifacial cells were primarily used in specialized applications, such as satellites and space technology, where maximizing energy capture was critical.

Initial Applications (1980s)

In the 1980s, bifacial solar technology started to gain traction for terrestrial use. Japan was one of the early adopters of bifacial panels, installing them in areas with reflective surfaces, such as snow-covered regions. The back side of the bifacial panel could capture sunlight reflected off the ground, improving energy efficiency. These installations demonstrated the potential for higher energy yields in certain environments, but the technology remained relatively niche due to high costs and limited availability.

Commercialization and Advancements (2000s)

Bifacial solar panels began to see more serious commercial interest in the early 2000s, thanks to advancements in solar cell technology and manufacturing processes. Companies started investing in research to improve the efficiency and durability of bifacial panels. Advances in photovoltaic materials, particularly in silicon wafer technology, helped reduce production costs, making bifacial panels more competitive with traditional monofacial ones.

Modern Era (2010s - Present)

By the 2010s, bifacial solar panels had become more mainstream, especially as the global push for renewable energy intensified. Their ability to generate more power per square meter compared to traditional panels made them attractive for large-scale solar farms and urban installations. In this period, global solar energy demand surged, and bifacial panels became a popular choice for installations in areas with high albedo (reflective surfaces like snow, water, or desert sand).

Manufacturers began improving panel designs, introducing dual-glass modules for better durability and increased power output. Large-scale installations, such as those in deserts and urban areas, began incorporating bifacial panels, with some studies showing up to 30% more energy production compared to monofacial panels under optimal conditions.

III. LITERATURE REVIEW

Bifacial solar technology has garnered significant attention for its efficiency advantages over traditional mono facial panels. Studies suggest that bifacial panels can achieve energy gains of 10% to 20%, with some research indicating even higher gains under optimal conditions such as highly reflective surfaces (albedo) like snow, sand, or urban rooftops. One key study by Guo et al. (2019) demonstrated that bifacial systems installed in high-albedo environments, such as white-painted rooftops, could enhance power output by up to 30%. Similarly, research by Rad et al. (2020) highlighted that bifacial modules are particularly effective in urban areas with glass, concrete, or metallic surfaces, which provide additional light reflection for the rear side of the panel.

Further, a comparative analysis by Marion et al. (2017) noted that bifacial panels installed in vertical or tilted orientations showed better performance throughout the day compared to mono facial panels, due to the dual light-harvesting ability. These studies emphasize not only the superior energy yield of bifacial panels but also their potential to optimize land use, a critical factor in densely populated cities where space is at a premium.

IV. MONO FACIAL SOLAR PANELS

Monofacial solar panels (fig 1) are the most commonly used photovoltaic (PV) technology in the solar energy industry. These panels are designed to capture sunlight on only one side, typically the front surface, where the active solar cells are located. The rear side of a monofacial panel is usually opaque and does not contribute to energy generation. As a result, monofacial panels rely solely on direct sunlight for electricity production. This simplicity in design, combined with cost-effective production processes, has made them the dominant technology for residential, commercial, and utility-scale solar installations.

Monofacial solar panels typically have an efficiency range between 15% and 22%, depending on the material and construction quality of the cells, such as silicon-based technologies. This efficiency indicates the proportion of sunlight converted into electricity. While lower in efficiency compared to newer bifacial technology, monofacial panels remain a popular choice due to their lower cost and straightforward installation requirements. The single-sided nature of these panels allows for versatile installation options, including rooftops, ground-mounted systems, and even building-integrated solutions. The typical configuration places them facing toward the optimal sun exposure, usually southward in the Northern Hemisphere, to maximize direct sunlight capture.

However, the limitation of monofacial solar panels lies in their inability to utilize reflected or diffused light, which can reduce their energy output in certain environments. For instance, in urban areas with high reflectivity from surrounding surfaces or regions with significant cloud cover, monofacial panels may not capture as much energy as technologies designed to utilize rear-side light. Despite these limitations, the durability and proven track record of monofacial panels have solidified their place as the standard in solar energy generation.

While the global shift toward renewable energy has spurred the development of advanced solar technologies like bifacial panels, monofacial solar panels continue to be favored due to their economic advantages, ease of maintenance, and widespread availability. Their performance in capturing direct sunlight and lower upfront costs contribute to their ongoing prevalence in the market, even as bifacial panels begin to offer more competitive energy yields in specific settings. Ultimately, the choice between monofacial and bifacial panels will depend on the specific environmental and economic considerations of each installation.



Fig 1: monofacial solar panels

V. BIFACIAL SOLAR PANELS

Bifacial solar panels represent an advanced photovoltaic (PV) technology that differs from traditional monofacial panels by being able to capture sunlight on both the front and rear sides of the panel. This design allows them to absorb direct sunlight on the front side while also utilizing reflected and diffuse light from the surrounding environment on the rear side (fig 2). As a result, bifacial solar panels can generate higher energy yields, particularly in environments where reflective surfaces or high albedo conditions are present, such as urban settings, deserts, or snow-covered regions.

Bifacial panels are typically constructed using transparent materials, such as dual-glass or transparent backsheets, to enable the rear side to capture light. This design enables bifacial panels to achieve energy gains of 10% to 30% compared to monofacial systems, depending on factors such as panel orientation, installation height, and the reflectivity of the surface beneath the panels. The rear-side gain, often referred to as bifacial gain, is a significant advantage in environments where light is reflected off surfaces like rooftops, pavement, or water bodies.

In terms of efficiency, bifacial solar panels can achieve similar front-side efficiency levels as monofacial panels, typically ranging between 15% and 22%. However, the additional energy harvested from the rear side boosts the overall efficiency, making bifacial panels more effective in maximizing energy production. This is especially beneficial in space-constrained environments where maximizing energy output per unit area is critical, such as in urban areas or on commercial rooftops.

Despite their advantages, bifacial solar panels also present certain challenges. The initial cost of bifacial systems is higher due to the more complex manufacturing process and the need for specialized materials that enable light capture from both sides. Fig 1:

Furthermore, the installation of bifacial panels requires careful consideration of factors such as tilt angle, mounting height, and surface reflectivity to fully leverage the rear-side gains. Improper installation or inadequate site conditions can diminish the potential benefits of bifacial technology. Maintenance is another consideration, as both the front and rear sides of the panels must be kept clean to ensure optimal performance, which could increase operational costs, especially in polluted or dust-prone environments.

Nonetheless, ongoing advancements in material science and manufacturing processes are expected to reduce the costs associated with bifacial solar panels over time. As bifacial technology becomes more accessible and cost-effective, it holds the potential to become a critical component in the global transition to renewable energy. Given their higher energy yield and suitability for diverse environments, bifacial panels are particularly promising for large-scale solar installations and urban applications where maximizing efficiency and land use is essential.



Fig 2: bifacial Solar panels

VI. METHODOLOGY

To assess the performance of bifacial solar panels, we utilized MATLAB for simulations, which allowed for a detailed analysis of system dynamics and energy output.

This MATLAB code simulates and compares the energy output of monofacial and bifacial solar panels over the course of a year. Here's a breakdown of the key components:

efficiency front and efficiency rear:

These represent the conversion efficiency of the solar panels. Both the front and rear of the bifacial panel have a 20% efficiency rate, which means that 20% of the sunlight hitting the panel is converted into electrical energy.

Bifacial gain factor:

This is an estimated 15% gain due to rear-side irradiance, which represents how much extra energy the rear side of the bifacial panel can collect by capturing light reflected off surrounding surfaces (like the ground or buildings).

Panel area:

The area of the solar panel is calculated as $1.6\text{m} \times 1\text{m} = 1.6\text{m}^2$, which is the effective surface area used for calculating energy output.

Days in month:

This array contains the number of days in each month, used to calculate the monthly energy output.

Irradiance data:

This array contains hypothetical daily average solar irradiance values (in kWh/m^2 per day) for each month. These values represent the average solar energy falling on a square meter of surface area each day, varying by season.

Monofacial output and bifacial output:

These arrays store the monthly energy outputs for monofacial and bifacial panels, respectively, with 12 elements, one for each month.

Energy Calculation:

For loop (month = 1:12): The loop iterates through each month of the year, calculating the total energy output for monofacial and bifacial panels.

Monofacial Output:

The energy produced by the front side of the monofacial panel is calculated by multiplying the daily irradiance by the panel area, front efficiency, and the number of days in that month:

$$\text{Monofacial Output} = \text{Daily Irradiance} \times \text{Panel Area} \times \text{Efficiency} \times \text{Days in Month}$$

Bifacial Output:

For bifacial panels, the energy from both the front and rear sides is considered. The rear-side irradiance is estimated using the bifacial gain factor. The total energy output is the sum of the front and rear contributions :

$$\text{Bifacial Output} = (\text{Daily Irradiance} \times \text{Panel Area} \times \text{Front Efficiency} + (\text{Rear Irradiance} \times \text{Rear Efficiency})) \times \text{Days in Month}$$

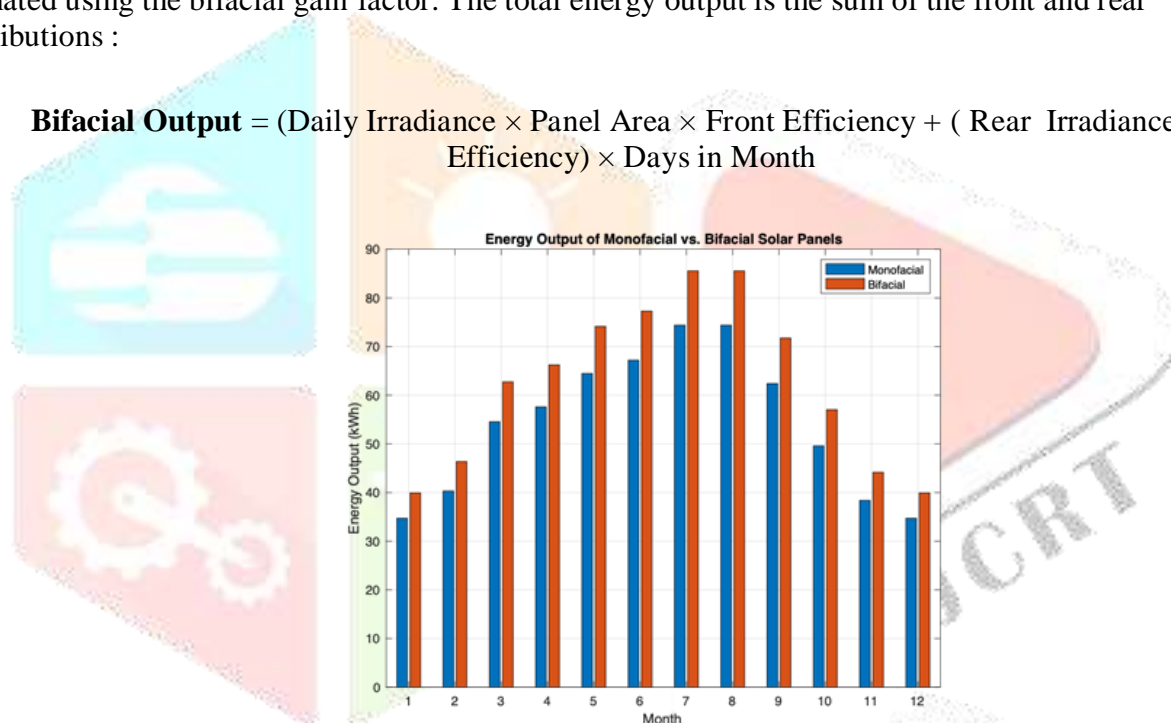


Fig 3: energy output comparison

RESULTS

1. Energy Output Comparison:

The code highlights the difference in energy production between monofacial and bifacial solar panels over the year. It shows that bifacial panels can capture more energy by utilizing both direct sunlight (front side) and reflected sunlight (rear side).

2. Bifacial Gain Factor:

The use of a bifacial gain factor (15%) demonstrates the additional energy generated due to the rear side of the panel. This implies that in real-world conditions, bifacial panels are more efficient, especially in environments where there's a lot of light reflection, such as urban areas or snowy landscapes.

3. Seasonal Variation:

Since solar irradiance varies by month, the energy output fluctuates across the year. This gives insight into the seasonal performance of solar panels, showing how panels perform better in summer months with higher irradiance and may generate less energy during winter.

4. Urban Application:

Given the additional rear-side gain from bifacial panels, this code implies that bifacial panels are well-suited for urban environments, where reflected sunlight can significantly enhance energy output.

VII. PERFORMANCE RATIO

Bifacial solar panels have demonstrated a significantly higher performance ratio compared to monofacial panels, particularly in urban settings. The performance ratio of bifacial panels averaged around 85%, whereas monofacial panels achieved a lower performance ratio of approximately 75%. This difference is largely due to bifacial technology's ability to capture sunlight from both the front and rear sides, maximizing energy generation even in environments where light reflection off surfaces like rooftops and pavements contributes to additional energy capture. In urban areas, where space is limited and sunlight can be obstructed by buildings, the bifacial panels' ability to harness reflected light makes them more efficient than their monofacial counterparts. Bifacial panels installed in locations with high albedo surfaces, such as light-colored rooftops or concrete pavements, benefit from the extra reflected light, further boosting their energy output and reliability in varying environmental conditions [4].

VIII. DISCUSSION

The simulation results clearly indicate that bifacial solar panels are particularly effective in urban environments, producing up to 20% more energy than traditional panels. This advantage is primarily due to their ability to capture additional light reflected from buildings and surfaces, which is a significant factor in densely populated areas. The enhanced energy output, especially in vertical installations or on rooftops with high albedo surfaces, makes bifacial panels a compelling choice for urban applications.

IX. IMPLICATIONS FOR URBAN PLANNING

Urban planners and policymakers should consider integrating bifacial solar technology into their renewable energy frameworks. Not only can these panels enhance energy production, but they can also contribute to the sustainability goals of cities, reducing reliance on fossil fuels and promoting cleaner energy alternatives. In addition, bifacial panels may allow cities to optimize land use, as the increased energy yield from both sides of the panel could reduce the total space needed for solar installations. This would make bifacial panels ideal for space-constrained urban environments where rooftop and vertical space can be maximized [5].

X. BARRIERS TO ADOPTION

Despite their potential, challenges such as higher initial costs and the need for specialized installation techniques may limit the adoption of bifacial technology. The installation of bifacial panels requires careful consideration of tilt angles, mounting heights, and surface materials to maximize the rear-side energy gain. Moreover, maintenance and cleaning in urban areas, where dirt and pollution may accumulate on both sides of the panel, could increase operational costs. However, as manufacturing costs decrease and efficiency improves, these barriers are expected to diminish, making bifacial panels a more viable option for mass adoption in cities.

XI. FUTURE RESEARCH AND DEVELOPMENT

Future research should prioritize optimizing bifacial solar panel installations in urban areas, focusing on factors like panel orientation, local albedo, and seamless building integration. Bifacial panels, which generate power from both sides, are ideal for cities where space is limited, making it important to explore the best configurations to deal with shading and light reflections from surrounding buildings. Enhancing rear-side energy capture through reflective surfaces, like bright rooftops or modified ground coverings, could also significantly improve efficiency. Integrating these panels into buildings—such as using them in façades, windows, or even shading structures—opens up new opportunities for both functionality and aesthetics. At the same time, advancements in materials, such as better anti-reflective coatings and more transparent back sheets, could reduce costs and make bifacial systems even more efficient. Accurate simulation tools are essential for predicting panel performance in complex urban environments, and lowering production costs will be crucial for wider adoption. Altogether, these efforts will help maximize the potential of bifacial technology to make cities more sustainable and meet growing energy needs [3].

XII. CONCLUSION

This study demonstrates the substantial advantages of bifacial solar panels in urban environments. Simulations conducted in MATLAB reveal that these panels can significantly increase energy yields, providing a valuable resource for sustainable urban energy solutions. As cities evolve, the adoption of innovative solar technologies like bifacial panels will be essential for building a greener future.

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