

## RESEARCH ARTICLE



# Performance Evaluation of a 70.6 kWp Building-Integrated Photovoltaic (BIPV) System using PVSol

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Received: 07-12-2024

Accepted: 16-01-2025

Published: 27-02-2025

**Citation:** Quddus AS, Usmani T, Hasan SH (2025) Performance Evaluation of a 70.6 kWp Building-Integrated Photovoltaic (BIPV) System using PVSol. Indian Journal of Science and Technology 18(7): 571-579. <https://doi.org/10.17485/IJST/v18i7.3972>

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Published By Indian Society for Education and Environment (iSee)

**ISSN**

Print: 0974-6846

Electronic: 0974-5645

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## Abstract

**Objectives:** Recent technological advancements have significantly improved the energy conversion efficiency of Building-Integrated Photovoltaic (BIPV) modules and Photovoltaic (PV) modules in general. These improvements have facilitated the widespread adoption of PV systems across various sectors, including residential, commercial, and industrial applications. The modular and distributed characteristics of PV systems make them a preferred choice among the diverse renewable energy technologies available. **Methods:** This study involves simulation analysis of a BIPV system using the PVSol solar PV system analysis tool and a comparison of energy generation & performance ratio with an actual rooftop PV system installed at Integral University, Lucknow, India. The study presents and discusses various parameters of the 70.6 kWp BIPV system for a geographical location of Lucknow having coordinates 26.84 N, 80.94 E. **Findings:** The BIPV technology is key to reducing global building energy consumption, which accounts for approximately 40% of total energy use, contributing to lower greenhouse gas emissions. 70.6 kWp rooftop PV system at Integral University in Lucknow, India, serves as a reference for BIPV system simulation, helping to validate its performance and improve system reliability. **Novelty:** The BIPV system of Integral University, Lucknow, is analysed and also simulated on PVSol, which is industrial software. When the technical parameters are compared and analysed, it is found that the average PR of the simulated system is 80.15, whereas the average PR of the installed system is 67.76%. This shows that system efficiency is approx. 84.54%.

**Keywords:** Building Integrated Photovoltaic System (BIPV System); MPPT; PVSol; Performance Ratio (PR); PVSyst Energy Generation Tool; Solar PV System

## 1 Introduction

The Building Integrated Photovoltaic system, also known as the BIPV system, is an engineered combination of building architectural design and solar photovoltaic technology. The core idea behind the BIPV system is the seamless integration of the BIPV system into the building envelope for proper aesthetics and looks of the building. With the climatic challenges the world is facing today, BIPV possesses a significant place in urban development, especially in modern architectural designs where the use of glass is extensive as building envelope material<sup>(1,2)</sup>.

BIPV system enhances the look of the building along with renewable energy onsite generation. Unlike Building Adapted Photovoltaic (BAPV) systems such as rooftop systems etc.<sup>(3)</sup>, the core objective of a BIPV system is to replace conventional building materials used in building construction such as roofs, facades, skylights, etc., with photovoltaic module which provides dual functionality, i.e., building envelope element + onsite energy generation source<sup>(4,5)</sup>. This combination results in space efficiency for integrating PV systems with buildings. Another good advantage of the BIPV system is that it acts as a weatherproofing system for the building, such as thermal insulation, noise reduction, and rain & wind protection, and it improves the building's aesthetics<sup>(6,7)</sup>.

Globally, energy consumption for buildings is growing due to urban development at an accelerated pace; it is estimated that around 40% of total global energy consumption is of buildings. This rise resulted in a significant increase in greenhouse gasses such as CO<sub>2</sub> emissions, which have adverse effects on the whole of the environment, as these effects are well known and established based on numerous scientific studies<sup>(8,9)</sup>. To mitigate or minimise these environmental adverse effects, BIPV technology is suitable due to its modular and distributed nature; it has the flexibility to be installed in commercial, residential, industrial and transport sectors<sup>(10,11)</sup>.

Government policies and incentives like feed-in tariffs have increased the adoption of photovoltaic systems worldwide in different sectors of the economy. Energy consumption from conventional grid sources was reduced considerably because of PV systems installed at universities, residential buildings, malls, commercial centres, etc.<sup>(12)</sup>

The geographical location of the BIPV system installation site plays a significant role in energy output as well as the overall development of the photovoltaic ecosystem. Metrological factors such as temperature and wind speed play a substantial role in the performance and production of PV system components, i.e., PV modules, inverters, cables, etc. Higher temperature reduces the efficiency and performance of the system due to losses such as de-rating loss. On the other hand, lower temperature increases the performance and efficiency of the PV system, given that solar insolation is good enough<sup>(13,14)</sup>.

The growing population requires adopting and advocating renewable energy systems, such as photovoltaic systems, to reduce higher loads on national electrical distribution networks and reduce the footprint of GHG gasses (CO<sub>2</sub>, NO, SO, etc.). Considering this, integrating renewable energy systems (PV systems) into the building envelope is crucial and will play a significant role in the future. Also, this PV integration will help achieve the smart grid's objectives for the power system sector<sup>(15,16)</sup>.

For the implementation of BIPV, the basic requirement is that the location must have good sunlight availability. This condition makes Lucknow suitable for the selection of a site situated in the northern part of India<sup>(17,18)</sup>. For the observation, the rooftop of the library building in Integral University has been selected due to many advantages, such as maintained infrastructure, easy accessibility, and a rated capacity of 70.6kWp. The data observed from the solar rooftop will be compared with PVSol software to verify and validate the PV system.

This paper is organized into 1. Introduction 2. Methodology 3. Results and discussion are concluded in section 4.

## 2 Methodology

### 2.1 BIPV System Description (PV Module & Inverter)

The simulation study for the 70.6 kWp BIPV system is performed for the geographical location of the city of Lucknow, having coordinates 26.84 N, 80.94 E and time zone UTC +5:30. The climate data for the system simulation is based on Meteoronorm 8.2, and data period is 2001 to 2020. The time resolution or step for BIPV system simulation is 1 minute yearly to include all seasonal variations. The 1-minute time step is to have as accurate simulation results as possible. Since the BIPV system is grid-connected, the grid parameters are 415 V, 50 Hz, and a power factor 0.9.

The PV module used in the system is the Flaxton 360 series manufactured by Bipod. The number of BIPV modules used is 196, each rated at 360 Wp, and it is installed at an inclination of 30 and an orientation of 180 (true south). The inverter used in the BIPV system is SUN2000-6KTL, manufactured by Huawei Technologies. It has 2 MPP trackers, and input per MPPT tracker is 2. Table 1 shows the technical parameters of the BIPV module and PV inverter. The flow chart shows the procedure for the study and analysis of the BIPV system.

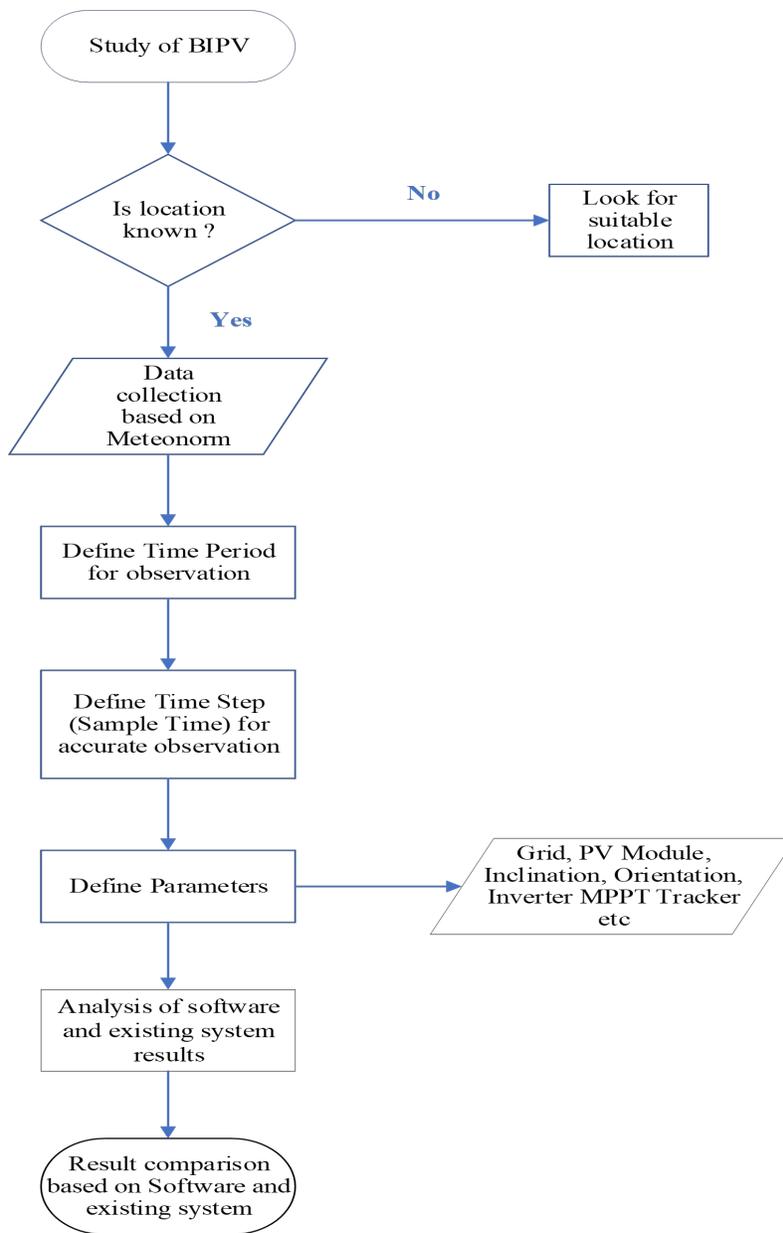


Fig 1. Flow chart generalized BIPV system analysis

Table 1. Technical Parameters of BIPV module & PV Inverter<sup>(19)</sup>

Electrical Performance at STC	Values	Unit
Nominal Power	360	Watt
Max Power Voltage (Vmpp)	93.83	Volt
Max Power Current (Imp)	3.84	Amp
Open Circuit Voltage (Voc)	115.95	Volt
Short Circuit Current (Isc)	4.41	Amp
Max Series Fuse Rating	10	Amp
Max System Voltage	1000	Volt
Cell Efficiency	15.5	%

Continued on next page

*Table 1 continued*

Temperature Coefficient of Pmpp	-0.268	[% / °C]
Temperature Coefficient of Voc	-0.209	[% / °C]
Temperature Coefficient of Isc	-0.0007	[% / °C]
<b>Inverter Input Parameters</b>		
Max Efficiency	98.6	%
Max PV Power	9,000	Watt
Max Input Voltage	1,100	Volt
Start-Up Voltage	200	Volt
Rated Input Voltage	600	Volt
Max. input current per MPPT	11	Amp
Max. short-circuit current	15	Amp
Number of MPP trackers	2	Numbers
Max. number of inputs	2	Numbers
<b>Inverter Output Parameters</b>		
Grid Connection	3	Phase
Rated Output Power	6,000	Watt
Max Apparent Power	6,000	VA
Rated Output Voltage	220/380, 230/400	3W N+PE
Rated AC Grid Frequency	50/60	Hz
Max Output Current	10.1	Amp

The BIPV system has 196 BIPV modules connected to the inverter. Also, MPP is given as follows: MPP1: 2 strings x 5 modules in series, MPP2: 2 strings x 5 modules in series, MPP3: 2 strings x 5 modules in series, MPP4: 3 strings x 3 modules in series and sizing factor are 115.2%. The output from BIPV modules comes to the junction box, and from there, it is fed to the inverter via a circuit breaker of 80 amps. Circuit breakers are recommended on either side of the inverter for safety and ease of maintenance. The output of the inverter is being fed to the grid operating at 415 V, 50 Hz.

### 2.2 Rooftop PV System description installed at Integral University, Lucknow

The rooftop PV system is installed at the Library Building of the Integral University. It has a total of 220 PV modules, each rated at 320 Wp, the brand is Vikram Solar. The total number of strings is 11, and the maximum number of modules in the series is 20. Inverters used in the system are 20 kW and 50 kW, Delta brand. The tilt of the module is 10 degrees, and the azimuth or orientation is 26 degrees southwest. The grid parameters to which the inverter is connected are 415 V, 3 phase, and 50 Hz.

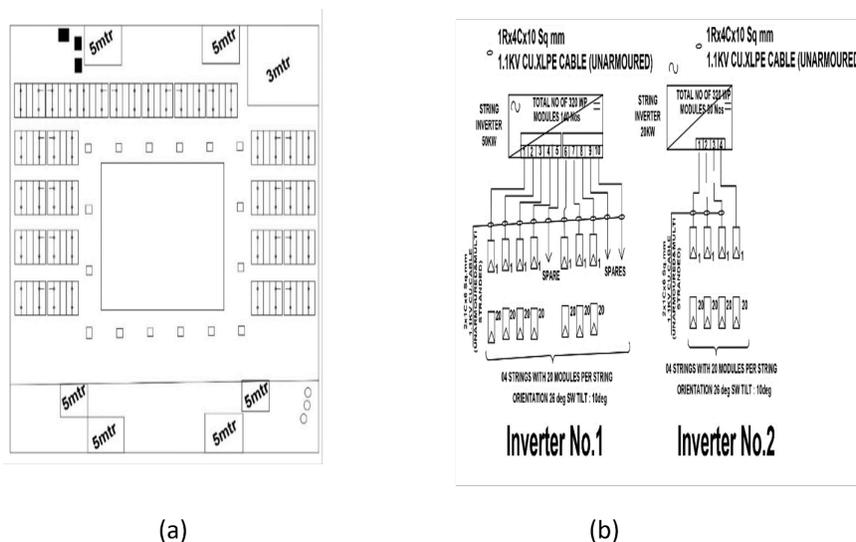


Fig 2. (a) Layout of 70.6 kW rooftop PV system, (b) String connection layout of rooftop PV system

Installed BIPV system at Integral University. It has 220 BIPV modules connected to the inverter. The output from BIPV modules is fed to the injection point. Circuit breakers are recommended on either side of the inverter for safety and ease of maintenance. The output of the inverter is being fed to a grid operating at 415 V, 50 Hz. PV string layout of rooftop PV system Inverter 1 (50 kW) has 07 strings with 20 PV modules connected in series per string, and Inverter-2 has 04 strings with 20 PV modules connected in series per string as shown in Figure 2(a) & (b). The Total modules are 120 (320 Wp each) & 80(320Wp each) respectively. The output of the inverter is being fed to the grid via the AC Distribution Box. The grid parameters are 415 V, 50 Hz, 3 phase. Technical parameters are given as (a) Input parameters are: max efficiency of 98.4%, max power PV of 21,000 Watts, max. voltage input of 1000V, startup voltage 250V, MPP voltage range of 520-800V, max. current MPPT input 50Amp, trackers and max. nos. input is 2 (b) Output parameters: grid connection is 3 phases, rated output power & max. Output power is 5.5kW, and rated output voltage and AC grid frequency are 220/380, 230/440 & 50/60 Hz, respectively. Parameter for Electrical Performance at STC is given as nominal power is 320Watt, max power voltage ( $V_{mpp}$ ) is 37.7V, max power current ( $I_{mpp}$ ) is 8.5A, open circuit voltage ( $V_{oc}$ ) is 46V, short circuit current ( $I_{sc}$ ) is 9.03A, max series fuse rating is 15A, max system voltage is 15A, cell efficiency is 16.49%, temperature coefficient of  $P_{mpp}$  is  $-0.38\%/osc$ , temperature coefficient of  $V_{oc}$  is  $-0.29\%/osc$  and temperature coefficient of  $I_{sc}$  is  $0.057\%/co$ .

### 3 Results & Discussion

#### 3.1 BIPV System Simulation

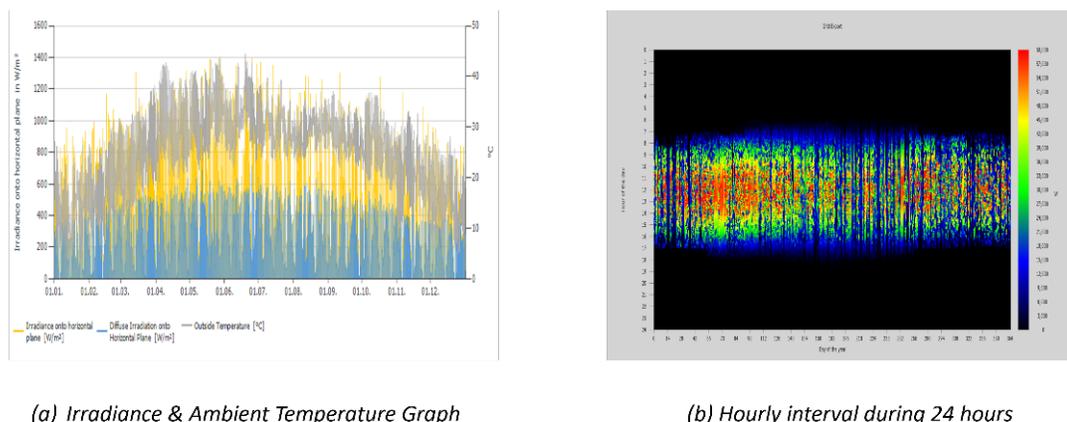


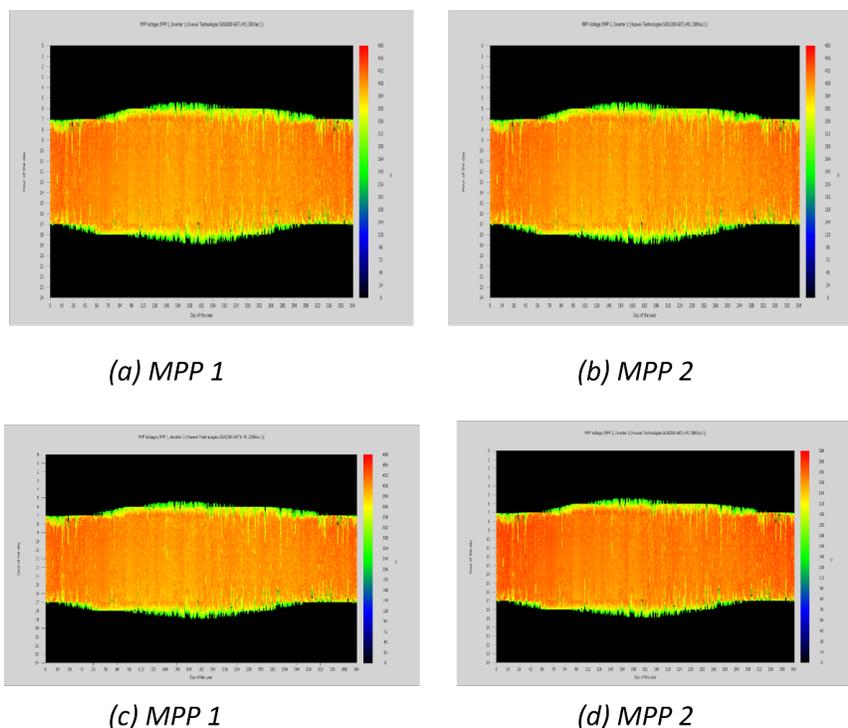
Fig 3. Temperature Graph

Lucknow (26.845249, 81.043083) is known and recognized for its subtropical climate, which has medium to high temperatures during different seasons of the year and good levels of rainfall and cloudy days. Based on the above figure, which shows irradiance and ambient temperature levels, the metrological parameters are impressive for electricity generation using a photovoltaic system. The average annual direct irradiance at one-minute resolution is  $249.53 \text{ w/m}^2$ , and diffused irradiance is  $88.22 \text{ w/m}^2$ . The average ambient temperature of  $28.71 \text{ C}$ . Minimum direct irradiance observed is  $154.39 \text{ w/m}^2$  on 17 Dec 9:11 AM, diffused irradiance on 11 Feb 9:23 AM, value is  $13.68 \text{ w/m}^2$ . Maximum direct irradiance was observed on 6th August 2024 at 12:29 PM; the value was  $1,408.32 \text{ w/m}^2$  and diffuse irradiance had a value of  $458.85 \text{ W/m}^2$ . Minimum energy generation is observed for January, with a value of  $5,891.7 \text{ kWh/month}$ , and maximum energy generation is observed for March, with a value of  $10,096.1 \text{ kWh/month}$ . The annual average monthly energy generation is observed at  $7,504.3 \text{ kWh}$ . The total yearly energy outflow from the inverter to the grid is  $90,052 \text{ kWh}$ , and the inflow is  $253 \text{ kWh}$  (standby consumption of inverter). Clipping losses are zero at the inverter. Figure 2(b) shows the annual grid export of the BIPV system at hourly intervals. Max grid export is observed from 10:00 AM to 3:30 PM, which is usually considered peak sun hours (PSH).

Figure 3 show an hourly graph for the MPP voltage range for MPP1 & MPP2 for Huawei Inverter. The graph shows that maximum MPP voltage is observed from 8 AM onwards till 5 PM during most months of the year. While minimum MPP voltage is observed between 7 AM to 8 AM and 5:30 PM onwards till 6:30/7:00 PM.

**Table 2. Overview of 70.6 kW<sub>p</sub> BIPV System Parameters<sup>(20)</sup>**

PV System	Values	Unit
PV Generator Output	70.56	kWp
Spec. Annual Yield	1,272.66	kWh/kWp
Performance Ratio (PR)	79.75	%
Grid Export	90,052	kWh/Year
Grid Export in the first year (incl. module degradation)	89,008	kWh/Year
Standby Consumption (Inverter)	253	kWh/Year
CO <sub>2</sub> Emissions avoided	42,206	kg/year



**Fig 4. MPP Graphs for Inverter 1(a, b) & 2(c, d)**

### Rooftop PV System

The rooftop PV system at Integral University is 70.4 kWp. PV modules are installed at a tilt of 10 degrees and an orientation of southwest. The monthly production data of the PV system for three consecutive years (2021, 2022 & 2023) is presented below in tabular form. Data is collected from the online dashboard of the rooftop PV system developed by QOS Energy’s Quantum Data Acquisition Module. This monthly generation data of the actual rooftop PV system will be compared with simulated generation data for the BIPV system to assess its validity and technical feasibility.

Table 3 presents the simulated energy generation data for the BIPV system throughout the year. It reveals that the average annual production is 7,504 kWh, while the actual rooftop PV system’s three-year average annual production is 7,442 kWh. The percentage difference between these two values isnegligible i.e., 0.83%, indicating that the simulated data is highly accurate and coincides with the actual production records.

Table 4 provides the Performance Ratio (PR) data for the rooftop PV system over three years (2021, 2022, and 2023). The lowest PR was recorded in July at 78.3%, and the highest PR was observed in January at 82.5%. The overall annual average PR value for the rooftop system was 80.15%. The table also includes simulated PR values for the BIPV system. For the simulated BIPV system, the lowest PR was again in July at 78.26%, while the highest was in January at 82.46%. The annual average simulated PR was also 80.15%.

**Table 3. Three-Year Energy Production Data**

Three-Year Energy Production Data- 70.4 kWp PV system-Integral University						BIPV Generation Data	
2021		2022		2023			
Month	Production (kWh)	Month	Production (kWh)	Month	Production (kWh)	Month	Production (kWh)
Jan	5090	Jan	4890	Jan	4940	Jan	5892
Feb	7110	Feb	7370	Feb	7220	Feb	7622
Mar	9660	Mar	9730	Mar	8690	Mar	10096
Apr	10300	Apr	9670	Apr	9410	Apr	9526
May	8270	May	9200	May	9840	May	9175
Jun	6330	Jun	8370	Jun	8970	Jun	7588
Jul	7360	Jul	8370	Jul	7890	Jul	6715
Aug	6620	Aug	8340	Aug	6960	Aug	6749
Sep	7130	Sep	6980	Sep	6910	Sep	7286
Oct	7980	Oct	5550	Oct	7730	Oct	7046
Nov	6120	Nov	6380	Nov	5490	Nov	6269
Dec	5510	Dec	6120	Dec	5400	Dec	6090
<b>Average</b>	<b>7290</b>	<b>Average</b>	<b>7581</b>	<b>Average</b>	<b>7454</b>	<b>Average</b>	<b>7504</b>

The lower PR values observed in certain months can be attributed to environmental factors such as soiling, temperature-related de-rating, maintenance, and system downtime. The highest PR recorded for the rooftop PV system occurred in March 2021 at 77.44%, while the lowest was in October 2022, at 52.46%. When comparing the simulated and actual values, a difference of 16.9%<sup>(15)</sup>.

**Table 4. Performance Ratio Data of Rooftop Pv for Three Years (2021, 2022 & 2023) <sup>(15)</sup>**

Performance Ratio (PR)						BIPV Generation Data	
2021		2022		2023			
Month	PR	Month	PR	Month	PR	Month	PR
Jan	68.32	Jan	68	Jan	65.21	Jan	82.46
Feb	74.07	Feb	70.9	Feb	69.49	Feb	81.79
Mar	77.44	Mar	70.33	Mar	71.06	Mar	81.24

*Continued on next page*

Table 4 continued

Apr	78.92	Apr	70.7	Apr	68.68	Apr	79.44
May	63.14	May	70.02	May	68.48	May	78.4
Jun	62.93	Jun	69.64	Jun	73.08	Jun	78.35
Jul	70.19	Jul	70.3	Jul	72.59	Jul	78.26
Aug	72.93	Aug	67.95	Aug	70.44	Aug	78.83
Sep	67.97	Sep	68.77	Sep	75.12	Sep	79.66
Oct	69.47	Oct	52.46	Oct	70.43	Oct	79.65
Nov	69.69	Nov	66.13	Nov	73.54	Nov	81.32
Dec	69.52	Dec	64.42	Dec	73.72	Dec	82.4
<b>Average</b>	<b>70.38</b>	<b>Average</b>	<b>67.47</b>	<b>Average</b>	<b>65.12</b>	<b>Average</b>	<b>80.15</b>

## 4 Conclusion

As per the simulation results of the 70.6 kWp BIPV system for Lucknow city that the system is technically feasible; concluding points are given below:

- The system shows an annual average performance ratio (PR) of 80.15%, compared to 67.66% for the actual rooftop PV system (which typically has a PR of around 70%).
- Minimum energy generation occurs in January, with the PVSol simulation showing 5,891.7 kWh, while the actual rooftop PV system generated 5,090 kWh in 2021 whereas maximum energy generation occurs in march (PVSol simulation: 10,096.1 kWh) and April 2021 for the actual rooftop system (10,300 kWh).
- The annual average monthly energy generation is 7,650.9 kWh in the PVSol simulation, compared to 7,442 kWh for the actual rooftop system. The specific yearly yield of the BIPV system is 1,272.66 kWh/kWp.
- A difference of 16.9% is observed between the simulated and actual energy generation values.

Further, these differences can be improved by employing different tracking methods to make our system more efficient.

## Acknowledgements

The authors of this article are thankful to Integral University, Lucknow, for providing support and communication reference no. IU/R&D/2025-MCN0003311. The opinions expressed here are solely the authors’ responsibility.

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