

# **Design and Techno-Economic Analysis of a Grid-Connected Roof Top Solar PV System: A PV\*SOL Based Case Study of KUET Medical Center**

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## **Abstract**

Bangladesh faces increasing energy demand and heavy reliance on fossil fuels, underscoring the urgent need for sustainable power generation through renewable sources. This study presents the design and techno-economic analysis of a grid-connected photovoltaic (PV) system with net metering for the KUET Medical Center, Bangladesh. The objective is to evaluate the technical feasibility and economic viability of utilizing solar energy to meet the facility's annual electricity demand of 15,500 kWh. The system design and performance assessment were conducted using the PVSOL simulation platform, incorporating 20 years of meteorological data for Khulna obtained from Meteosyn. A detailed 3D rooftop model was developed to optimize module orientation, tilt angle, and shading conditions. The proposed Configuration comprises 188 First Solar FS-6425 PV modules and seven LG ESS HOME 10 inverters. Simulation results demonstrate that the designed PV system can fully offset the center's annual energy consumption while exporting surplus power to the national grid under the net metering framework. The financial evaluation indicates a payback period of approximately 21 years, confirming the system's long-term economic sustainability. Beyond cost savings, the system enhances energy security, reduces carbon emissions, and supports Bangladesh's

renewable energy expansion goals. The findings validate the suitability of PVSOL as an effective simulation tool for institutional rooftop solar design. Future work may include field validation and techno-economic optimization integrating demand response and dynamic load profiling.

## **Keywords**

Grid-connected PV system, Net metering, PVSOL simulation, Techno-economic analysis, Renewable energy.

## **1. Introduction**

The increasing demand for renewable energy sources is currently driving a significant transformation in the global energy sector, necessitating the adoption of photovoltaic (PV) technology as a sustainable and scalable solution for electricity generation worldwide. A photovoltaic cell, commonly known as a solar cell, serves as a non-mechanical device that converts sunlight directly into electricity, offering diverse applications ranging from water heating and illumination to powering off-grid systems. In the context of Bangladesh, the integration of PV technology is critical for improving energy access and enhancing energy resilience. Currently, the country's energy mix is heavily dependent on fossil fuels, with gas accounting for 52.7% and furnace oil for 19% of generation. Shifting towards solar energy provides an opportunity to reduce this dependency on imported fuels, mitigate environmental impacts, and stimulate job creation and economic growth (Figure 1).

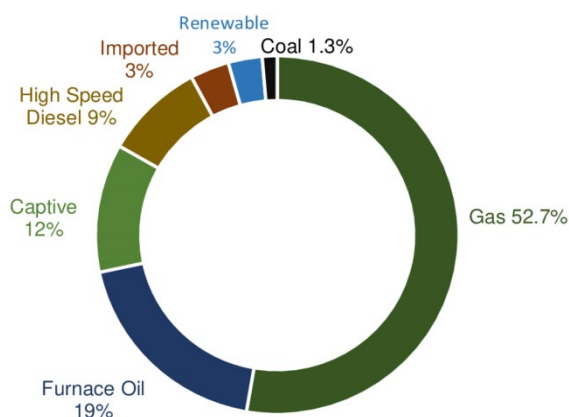


Figure 1. Energy mix in power generation of Bangladesh (including captive and solar home systems) (Alam, 2019)

This paper presents a detailed design and calculation of a grid-connected Solar PV system with net metering, utilizing the PV\*sol simulator for a case study at the KUET Medical Center. The primary objective is to assess the technical and economic viability of a rooftop system designed to meet the center's annual energy consumption of 15,500 kWh. The methodology follows a structured approach, beginning with the assessment of climate data collected from Khulna over the last 20 years and defining specific electrical consumption patterns.

The study proceeds to implement a 3D design comprising 188 PV modules and 7 inverters, specifically selected to optimize performance on the medical center's rooftop. Finally, the paper evaluates the simulation results to determine financial parameters, demonstrating that the design not only fulfills the facility's energy requirements but also supplies surplus energy to the grid, achieving a return on investment within 21 years.

### **1.1 Objectives**

- To assess the specific energy requirements of the KUET Medical Center by analyzing its annual electrical consumption patterns.
- To implement a comprehensive 3D design of the rooftop photovoltaic system using the PV\*SOL simulator to determine optimal module placement.
- To design a grid-connected PV system integrated with net metering capabilities to effectively manage surplus energy generation.
- To consider the economic viability of the proposed project by evaluating financial parameters and determining the return on investment period.

## **2. Literature Review**

The global shift towards renewable energy is accelerating, driven by the dual necessity of ensuring energy security and mitigating the adverse effects of climate change. Photovoltaic (PV) technology has established itself as a cornerstone of this transition, offering scalable solutions ranging from utility-grade power plants to decentralized residential systems. As the adoption of grid-connected PV systems grows, particularly in developing nations, the reliance on accurate simulation tools to predict performance and economic viability has become paramount. This review synthesizes recent findings regarding simulation methodologies, performance analysis in tropical climates, and the financial impact of net metering policies. Validating simulated designs against real-world operational data is a primary focus of current solar engineering research. Kumar and Sudhakar (2015) conducted a foundational study on a 10 MW grid-connected solar PV plant in Ramagundam, India. Utilizing PVsyst software, they evaluated the plant's output against local weather data. Their analysis revealed a Capacity Utilization Factor (CUF) of 17.25% and a Performance Ratio (PR) of 86.12%. Kumar and Sudhakar (2015) emphasized that high ambient temperatures in tropical regions significantly degrade voltage parameters, a critical design consideration for similar climates in South Asia.

In a comparative study focused on residential scale systems, Shukla (2016) analyzed a 110 kWp grid-connected installation on a building in India. The study aimed to benchmark the accuracy of different simulation tools, specifically PVsyst and Solargis. Shukla (2016) reported a specific energy yield of 1733 kWh/kWp/year but highlighted that simulation software often underestimates losses due to dust and thermal effects. The findings suggested that while simulation tools are robust, real-world performance in dusty urban environments can deviate by 5-10% if soiling losses are not aggressively modeled (Shukla, 2016).

The Role of 3D Modeling While 2D simulations have historically dominated the field, recent literature advocates for 3D modeling to address complex shading in urban environments. Aluko (2023) utilized PV\*SOL software to design a grid-connected system for a residential building in Lagos, Nigeria. Unlike standard 2D approaches, Aluko (2023) leveraged the 3D visualization capabilities of PV\*SOL to model the specific impact of building orientation and nearby obstructions. The study forecasted a Levelized Cost of Energy (LCOE) of \$0.056/kWh, demonstrating that precise shading analysis is essential for accurate financial modeling in modern architectural contexts (Aluko, 2023).

Research within Bangladesh has surged in response to national renewable energy targets. Bhuiyan (2020) investigated the technical feasibility of decentralized solar by analyzing a 5.2 kW grid-connected system in Noakhali. Using Meteornorm data for simulation, Bhuiyan (2020) projected an annual generation of 8.24 MWh and a specific yield of 4.34 kWh/kWp/day. The study highlighted the environmental impact, estimating a carbon emission reduction of 145 tons over the project's life. Bhuiyan (2020) concluded that grid-connected systems are technically viable even in coastal regions where irradiance can fluctuate.

Similarly, Chowdhury (2021) explored the techno-economic potential of a 10 kW system in Dhaka. The study focused on the concept of "grid-parity," suggesting that solar power is becoming cost-competitive with conventional grid electricity. Chowdhury (2021) demonstrated that optimizing the tilt angle of PV panels could increase annual energy capture by up to 5%, a significant gain for space-constrained rooftops.

The implementation of Net Metering Guidelines in 2018 revolutionized the economic landscape for solar in Bangladesh. Hossain (2021) provided a detailed analysis of a net-metered system in Dhaka, simulating the cash flows between the consumer and the utility. The results indicated a payback period of just 5.9 years, making the investment highly attractive. Hossain (2021) argued that the financial viability of rooftop solar is now heavily dependent on policy mechanisms like net metering, which allows for a positive Net Present Value (NPV) by offsetting expensive grid electricity (Hossain, 2021).

This paper addresses a specific gap in the current literature regarding solar energy implementation in Bangladesh. While Bhuiyan (2020) and Hossain (2021) have provided valuable insights into residential systems using 2D simulations like PVsyst, there is a lack of research focused on institutional buildings with complex roof structures. This research work is important because it employs PV\*SOL, a tool capable of advanced 3D shading analysis, to model the KUET Medical Center. Unlike simple residential roofs, this site features multiple elevations and potential self-shading that standard 2D models cannot accurately quantify. Furthermore, this study applies Net Metering

calculations to a commercial load profile in Khulna, providing a regionally specific economic assessment that differs from the Dhaka-centric studies found in existing literature (Table 1).

Table 1. Summary of key literature on the design, performance analysis, and economic feasibility of grid-connected photovoltaic systems

SL	Topic	Output	Software / Experimental	Country	References
1.	Performance of Utility Plant	10 MW capacity; 17.25% CUF; 86.12% PR.	PVsyst (Simulation)	India	Kumar and Sudhakar (2015)
2.	Residential System Analysis	110 kWp; 1733 kWh/kWp/yr yield; loss analysis.	PVsyst & Solargis (Simulation)	India	Shukla (2016)
3.	3D Design & Economics	LCOE \$0.056/kWh; High ROI; Shading model.	PV*SOL (Simulation)	Nigeria	Aluko (2023)
4.	Coastal Residential Study	8.24 MWh/yr generation; 4.34 kWh/kWp/day.	PVsyst (Simulation)	Bangladesh	Bhuiyan (2020)
5.	Net Metering Economics	Payback 5.9 years; +NPV; 78% Performance Ratio.	PVsyst (Simulation)	Bangladesh	Hossain (2021)
6.	Grid-Connected Feasibility	Cost reduction strategy; Carbon emission analysis.	PVsyst (Simulation)	Bangladesh	Chowdhury (2021)
7.	Solar Irradiance Assessment	Monthly average daily global solar radiation.	Experimental (Data)	Bangladesh	Mondal (2011)
8.	Thin Film Technology	Performance of a-Si technology in warm climates.	Experimental	India	Kichou (2016)
9.	Cost of Energy (LCOE)	Comparative cost analysis of different sources.	Analytical	Global	Branker (2011)
10.	Grid-Connected Performance	5 kWp system; 16.3% CUF; 78% PR.	Experimental	Ireland	Ayompe (2011)
11.	Solar Potential Study	Energy potential assessment for varied landscapes.	Analytical	Bangladesh	Halder (2015)
12.	Renewable Energy Scenario	Review of renewable energy status and goals.	Literature Review	Bangladesh	Islam (2014)
13.	Performance at High Temp	Impact of temperature on 20 kWp system.	Experimental	India	Padmavathi (2013)
14.	Grid Parity Analysis	Global overview of PV grid parity dynamics.	Analytical	Global	Breyer (2009)
15.	Hybrid System Analysis	Feasibility of PV-Diesel hybrid systems.	HOMER (Simulation)	Malaysia	Lau (2010)
16.	Dust Impact on PV Output	4.48% efficiency loss; 20.54 MWh/yr loss.	Experimental & GIS	Bangladesh	Protya et. al. (2025)

### 3. Methodology

The design and feasibility analysis of the grid-connected photovoltaic (PV) system for the KUET Medical Center was conducted using a systematic approach facilitated by the PV\*SOL simulation software. The methodology adopted for this study is illustrated in Figure 2 and involves the following key stages:



Figure 2. Methodology flowchart

### 3.1. Site Assessment and Data Collection

The study began with a comprehensive assessment of the project site located at the KUET Medical Center in Khulna, Bangladesh. To ensure accurate simulation results, historical climate data for the specific coordinates of Khulna were aggregated. Meteorological data spanning the last 20 years, including solar irradiance, ambient temperature, and wind speed, were retrieved using the Meteodyn database integrated within the simulation tool. This data provided the baseline for estimating the solar energy potential of the site. The longitude & latitude for KUET medical center is 22.85° & 89.54°. Average solar radiation for Khulna, Bangladesh is given in Figure 3.

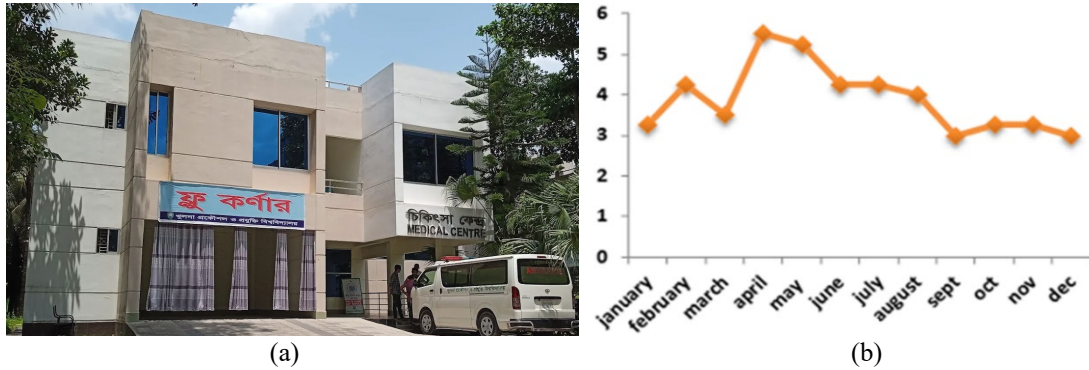


Figure 3. (a) KUET medical center, (b) Average solar radiation in Khulna division for 2023

### 3.2. Load Profiling and System Definition

A detailed electrical load profile was established to determine the system's capacity requirements. The annual energy consumption of the medical center was defined as 15,500 kWh based on the facility's electrical appliances and usage patterns. The system topology was defined as a grid-connected PV system coupled with net metering capabilities, allowing for the export of surplus energy to the national grid (Figure 4).

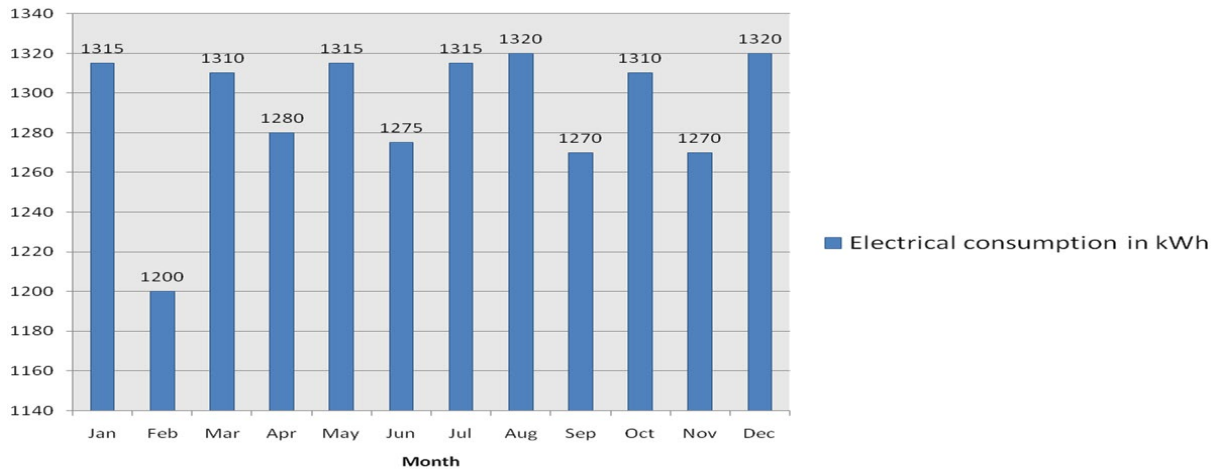


Figure 4. Monthly energy consumption of KUET Medical Center.

### 3.3. Component Selection and Simulation Parameters

The core components of the PV system were selected based on efficiency and compatibility with the local climate.

- **PV Modules:** The First Solar FS-6425 thin-film module was selected for the array. This module has a nominal power of 425 W and an efficiency of 17.2%, making it suitable for the available rooftop area.
- **Inverters:** To convert the DC output, the LG ESS HOME 10 inverter was chosen. This three-phase inverter has a rated output power of 10 kVA and a maximum efficiency of roughly 97%, ensuring optimal energy conversion.

### 3.4. 3D Modeling and System Design

A precise 3D model of the KUET Medical Center was constructed within the PV\*SOL environment to visualize the building geometry and assess shading impacts. The design process involved:

- **Module Placement:** A total of 188 PV modules were strategically placed on the rooftop to maximize irradiance exposure while minimizing inter-row shading.
- **Configure ration:** The modules were configure red into specific arrays and connected to 7 units of LG ESS HOME 10 inverters.
- **Cabling:** A detailed cable plan was generated to interconnect the 188 modules, optimizing the cable runs to reduce ohmic losses (Figure 5, Table 2- Table 3).

Table 2. Ratings of First solar Fs-6425 module under standard conditions

Nominal Values	Symbol	FS-6425
Nominal Power	$P_{max}$ (W)	425.0
Efficiency (%)	%	17.2
Voltage at $P_{max}$	$V_{max}$ (V)	181.5
Current at $P_{max}$	$I_{max}$ (A)	2.34
Open Circuit Voltage	$V_{OC}$ (V)	218.9
Short Circuit Current	$I_{SC}$ (A)	2.54
Maximum System Voltage	$V_{SYS}$ (V)	1500
Limiting Reverse Current	$I_R$ (A)	5.0
Maximum Series Fuse	$I_{CF}$ (A)	5.0

Table 3. Ratings of LG ESS HOME 10 under standard conditions

DC input	Value	AC output	Value
Max. Input Voltage	1000V	Rated Grid Voltage	3-NPE 400V / 230V
Min. Input Voltage	150V	AC Voltage Range	319 ~ 458V / 184 ~ 264.5V
Max. DC Power (per channel)	13.5kW (7.5kW)	Frequency	50 Hz
Input Voltage Range MPPT	275 - 800V	Rated Output Power	10kVA
Number of MPPT	3	Rated Output Current	14.4A
Number of String per MPPT	1	THD / Power Factor	< 5% / $\pm 0.8$
Max. Input Current per MPPT	13A	Phases	3

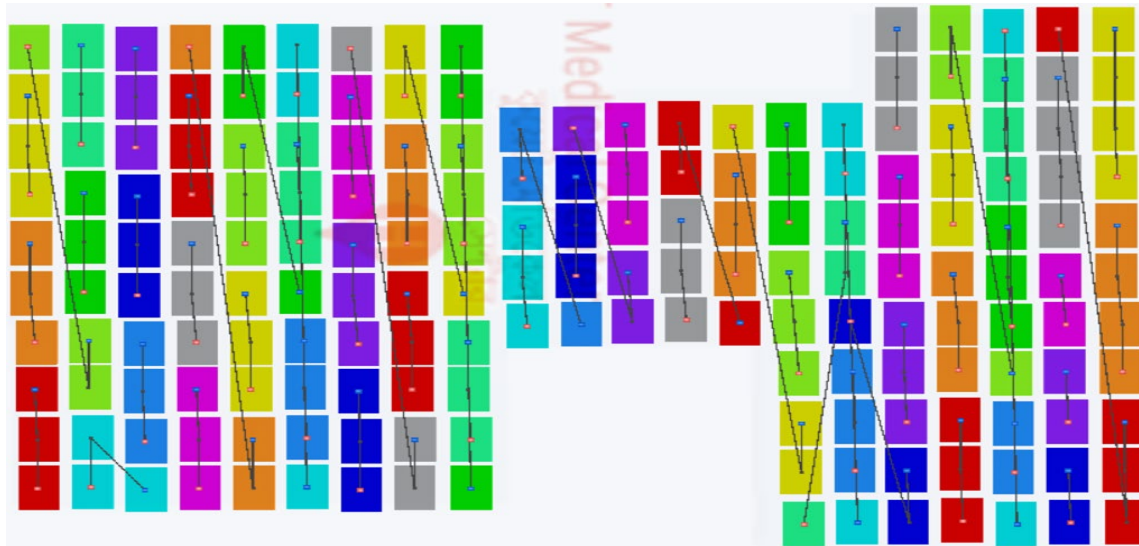


Figure. 5. Cable design for all 188 modules mounted on KUET medical center.

### 3.5. Techno-Economic Analysis

Following the technical design, a financial analysis was defined to evaluate the project's economic viability. Key financial parameters, including installation costs, operation and maintenance (O&M) expenses, and feed-in tariff rates, were input into the simulation. The software then computed critical economic indicators such as the Return on Investment (ROI), Payback Period, and Accrued Cash Flow over the project's lifespan to validate the feasibility of the proposed design (Figure 6).

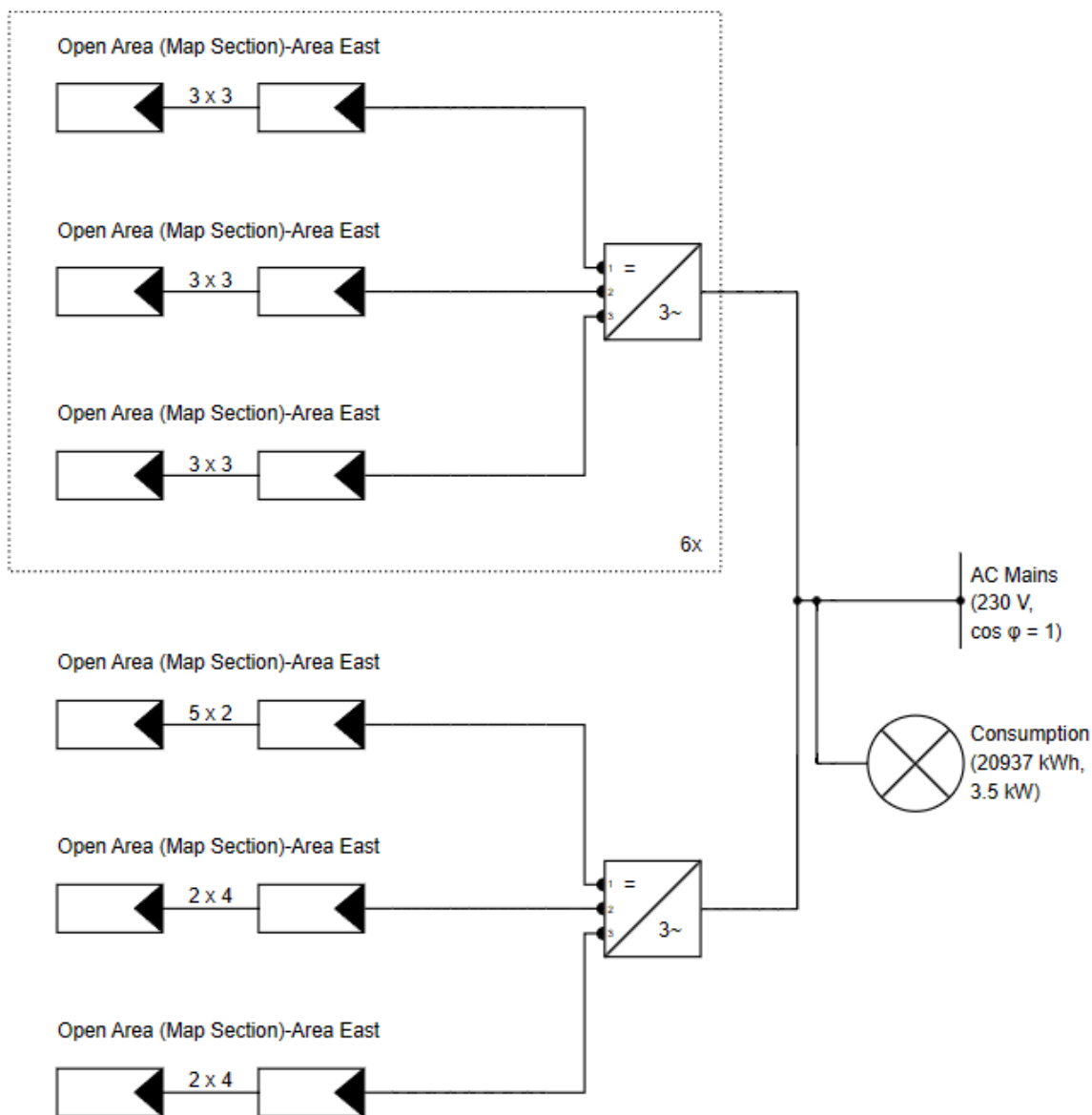


Figure. 6. Circuit diagram for the PV mounted KUET medical center.

### 4. Result and Discussion

After compiling all the input parameters, the simulation tool provides different results for different section of the solar photovoltaic system. These relate to the system's performance, the yearly production prediction, the performance ratio, and other things. Aside from this, other financial results are also determined by the PVSOL and are covered in detail in the section that follows.

#### 4.1 Load calculation

The annual energy consumption for KUET Medical Center is to be determined through observation and simulation. The experimental values are obtained over a day using power analyzer. A total of 286 datasets of Line voltage, Phase Voltage, Current, Real Power, Reactive Power, Power Factor etc. was found throughout the day using power analyzer. Then the collected daily electric consumption in (kWh) was simulated for a whole year using Design Builder Application which gives the annual energy consumption of KUET medical center (Figure 7).

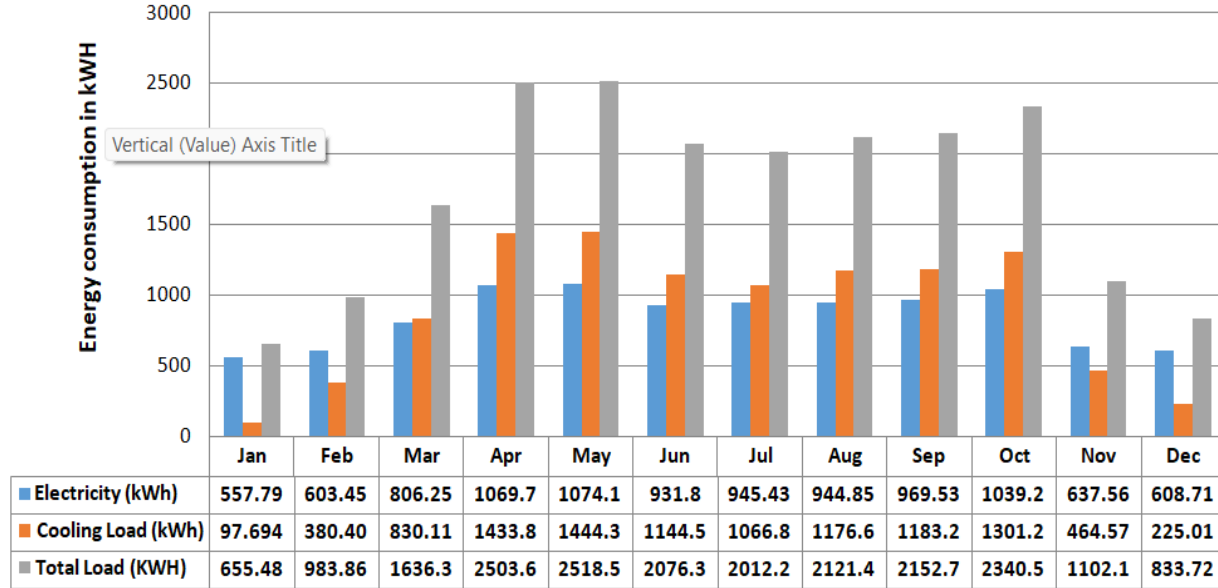


Figure. 7. Energy consumption for KUET medical center over a year.

#### 4.2. Energy Production Analysis

The simulation results indicate a robust energy generation profile throughout the year. The system, comprising 188 First Solar FS-6425 modules, is projected to generate a total annual energy output that significantly exceeds the medical center's annual consumption of 15,500 kWh. As illustrated in Figure 2, the energy generation peaks during the spring months (March to May), coinciding with high solar irradiance and relatively lower cloud cover in Khulna. Conversely, a dip in production is observed during the monsoon season (June-July) due to increased cloud density and precipitation. Despite these seasonal variations, the specific yield of the system remains high, validating the optimal tilt angle and orientation selected during the 3D design phase (Figure 8).

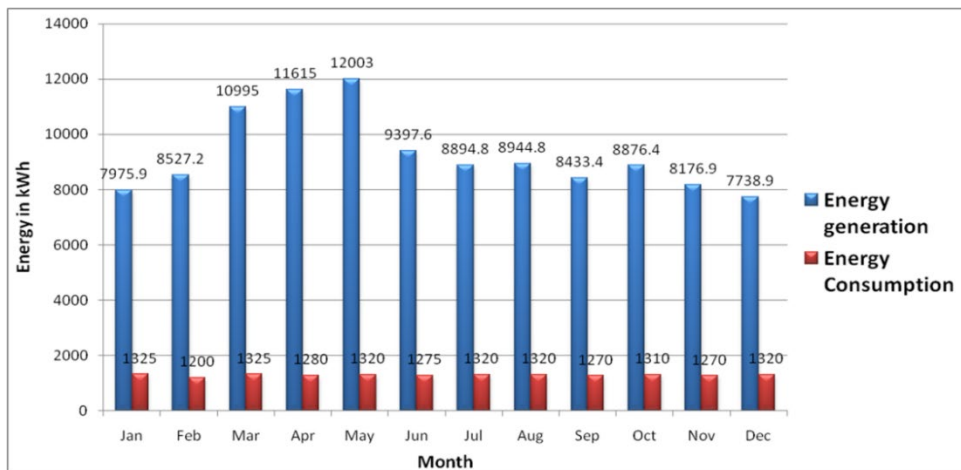


Figure. 8. Annual monthly production forecast with consumption.



#### 4.5 Energy flow graph

The energy flow within a photovoltaic (PV) solar energy system that is connected to the grid is shown visually by the grid-connected energy flow graph in Figure. 11. The flow of energy is represented by arrows, which show how electricity moves from solar panels to inverters where it is transformed into useful AC power.

#### 4.6 System Performance

By performing simulation on PVSOL, we get following results as output of the system. From this simulation we have got 89.9 kW solar system which fairly suitable for the utility location. And this system can deliver 111,580 units per year (Table 4) which is sufficient for consumption of KUET Medical center.

Table 4. PV system output for KUET medical center

Parameter	Quantity	Unit
PV Generator Output	79.9	kWp
Specific Annual Yield	1376.18	kWh/kWp
Performance Ratio (PR)	83.3	%
Yearly Generation	111,580	kWh/year
Grid Feed-in	99,495	kWh/year
CO <sub>2</sub> Emissions avoided	51,680	kg/year
Energy Generated per kg of CO <sub>2</sub> Emissions avoided	2.16	kWh/kg

#### 4.7 Economic Feasibility Analysis

The economic viability was assessed based on the initial capital cost (CAPEX), operation and maintenance costs (OPEX), and the savings accrued from avoided grid electricity purchases. As shown in the cash flow trajectory (Figure 12), the system demonstrates a positive financial outlook over its lifespan. While the initial investment is significant, the cumulative savings allow the project to break even. The simulation indicates a Payback Period of 21 years. While this period spans a significant portion of the system's operational life, it confirms that the project will eventually recover its costs and generate profit, providing long-term energy security for the institution.

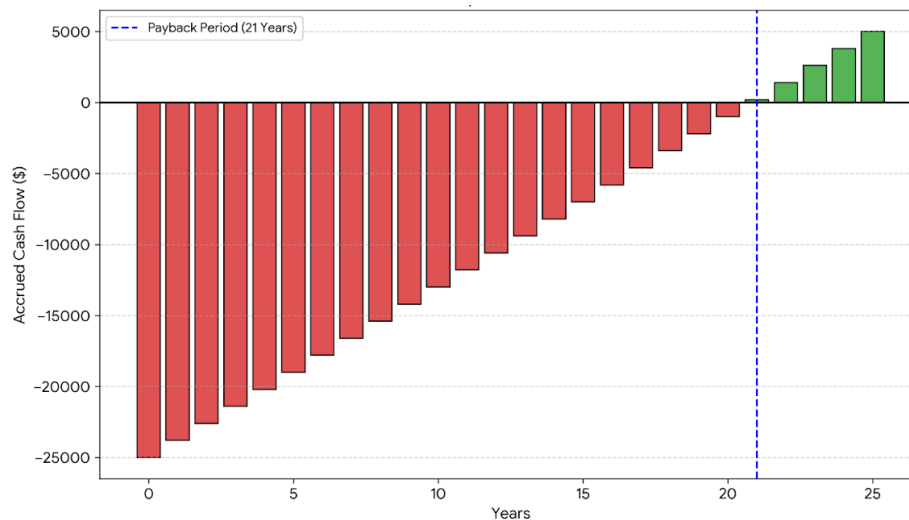


Figure 12. Cash flow

### 5. Conclusion

This study successfully demonstrates the technical and economic feasibility of a grid-connected photovoltaic (PV) system for the KUET Medical Center. Utilizing the advanced 3D modeling capabilities of PV\*SOL software, the research optimized the placement of 188 thin-film modules to mitigate shading effects and maximize energy capture in the specific climatic conditions of Khulna.

The simulation results confirm that the proposed system is capable of generating sufficient clean electricity to fully meet the medical center's annual demand of 15,500 kWh. Furthermore, the integration of net metering allows for a significant export of surplus energy to the national grid, transforming the institution from a passive consumer into an active energy producer. Economically, the project projects a payback period of 21 years. While this represents a long-term investment, the positive accrued cash flow and protection against rising utility rates validate its financial viability. Beyond economics, this implementation serves as a sustainable model for institutional buildings in Bangladesh, contributing to the reduction of fossil fuel dependency and carbon emissions. Future research should focus on validating these simulation models with real-time field data to further enhance prediction accuracy and explore the integration of battery storage for increased energy resilience.

## 6. Future Recommendations

Based on the findings of this study and the operational context of the KUET Medical Center, the following areas are recommended for future research and implementation:

- **Validation with Field Data:** Post-installation, a comparative study should be conducted between the real-time energy generation data and the PV\*SOL simulation results. This will help quantify local loss factors, such as specific soiling rates and thermal degradation in Khulna, more accurately.
- **Integration of Energy Storage:** Future work should evaluate the techno-economic feasibility of integrating a Battery Energy Storage System (BESS). A hybrid system would enhance energy resilience, ensuring uninterrupted power supply to critical medical equipment during national grid load-shedding events.
- **Smart Monitoring Implementation:** The adoption of IoT-based smart monitoring systems should be explored. Real-time data tracking at the inverter or string level would facilitate predictive maintenance, allowing for immediate detection of faults or underperforming modules to minimize downtime.
- **Lifecycle Assessment (LCA):** A comprehensive environmental analysis, including the carbon footprint associated with the manufacturing and eventual disposal of the thin-film modules, is recommended to evaluate the project's net sustainability over its entire lifecycle.
- **Expansion Feasibility:** This study should serve as a baseline for assessing other institutional buildings within the KUET campus. Future research could assess the viability of interconnecting these individual rooftop systems to form a centralized campus microgrid.

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