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Case Report

Developing A Net-Positive Energy Building: A Case Study of Library Building of Central University of Rajasthan

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A B S T R A C T

The need for energy in the building sector in the last few decades has increased manyfolds which has resulted in a significant increase in carbon emissions. The building sector accounts for around 40% of the energy consumption, and with the growing economy and a steady increase in per-capita building space, energy consumption in the building sector is bound to increase. In recent years, efforts have been made to address this issue by adopting green buildings, sustainable development, and net-zero buildings. Most of the green rating systems prevalent in India focuses on energy efficiency and energy savings in buildings, but limited research exists on library building's energy-saving potential due to modeling complexities. These complexities include variability in footfall, construction typology, and potentially more sophisticated architectural planning. This paper examins the possibility of achieving net-positive energy goals for a library building which includes solar photovoltaic and wind energy systems. Several factors were considered when determining the size of the photovoltaic system using PVsyst software for installation in buildings, such as roof area, shading, and PV panel efficiency. It was found that the EPI calculated for library building is significantly lower in comparison to the benchmarks provided by various rating systems for educational buildings. Also, renewable strategies can effectively reduce dependency on on-grid electricity supply and help in creating net-zero energy buildings. Moreover, advancing solar PV technology will enable net-positive energy goals for library buildings having low EPI.

Keywords: Institute, Library, PVsyst, Energy Simulation, Low Energy Building, Net-Positive Energy Building

Introduction

India's energy sector is constantly grappling with the task of generating clean energy due to the escalating energy needs, which have put a strain on the nation's energy landscape and led to increased carbon emissions. To address these issues, all energy-consuming sectors need to focus on low-carbon buildings, energy efficiency, energy generation and optimisation of energy needs. The construction industry, responsible for 40% of overall energy consumption,[1] must prioritise energy optimisation by implementing energy-efficient practices and incorporating renewable energy sources. Net-positive energy buildings are seen as a solution to reducing the overall carbon footprint of the building sector. In the last decade with the invention of technological advances, there has been a gradual shift from net-zero to net-positive energy buildings.[2] In fact, net zero is regarded as the bare minimum for sustainable architecture[3]; creating a better building will only help humanity fight against energy-generated global issues.

Educational buildings often do not receive much attention for their energy efficiency compared to commercial buildings, specifically in the case of government universities/ institutions due to low Energy Performance Index in comparison to various standards/ benchmarks.[4] Nevertheless, these buildings can serve as real-life examples for designing energy-efficient structures and can set a good example for the local community by sharing knowledge.[5]

The library is a crucial structure within educational institutions and is always bustling with activity. It poses a difficulty in attaining energy efficiency because its occupancy levels fluctuate throughout the day. For this paper, a case study approach is used to analyse the possibility of net-positive library building through renewable energy. Net-positive energy buildings (NPEBs) refer to buildings that produce more energy than they consume and typically distribute the excess clean energy to the surrounding grid.[6] This is the key towards achieving the Sustainable Development Goals and carbon neutrality[7].

For this study, PVsyst 7.4.8 software was used to check the possibility of mitigating the energy demand of the university library building through a solar photovoltaic system. Many researchers have used PVsyst to estimate the performance of the system.[8] The possibility of integrating this solar PV system with the building-integrated wind turbine system is also addressed to evaluate the possibility of making the library building net positive in terms of energy. Matai (2013) demonstrated the applicability of a solar wind hybrid system for the central University of Rajasthan.[9]

Some factors that directly influence the sizing of a solar PV system are studies, namely the area of the roof, shading factor, inverter size, and module size. It was found that the roof area of the library building can be used effectively for achieving net-positive energy building targets for a library building.

Literature Review

Building and its allied fields consume around 40% of the total energy consumption.[1] The large existing building stock and upcoming building stock to mitigate ever-increasing demand have further increased energy consumption in absolute terms. The energy demand in India has been growing at a relatively constant rate during the last decade, and energy consumption in the domestic and commercial sectors has increased exponentially from 2000 to 2017.[10] India's per capita energy consumption is still low compared to developed nations but is growing at a steady rate till 2019. India, owing to its large population and large existing building stock and to mitigate this ever-increasing energy demand, renewable energy, energy conservation, and energy efficiency are sighted as measures. A small intervention in terms of mitigating power from renewable sources can reduce the burden on fossil fuels.

Conserving energy and rehabilitating existing buildings can reduce climate impact in terms of GHG emissions and energy costs.[11] To mitigate energy demand, renewable energy is a need of the hour so that dependency on conventional resources can be decreased. The energy demand can be fulfilled through renewable energy resources, such as solar photovoltaic systems.[12] Renewable energy resources commonly used for building applications including solar, wind, geothermal, biomass, etc., can effectively reduce the dependency on conventional sources and hence reduce the carbon footprint of the building. In this case, the EPI of the building might not be compromised as energy is generated from relatively clean sources.

Before selecting an appropriate renewable energy technology to apply to an existing building retrofit project, it is essential to consider the availability of these resources in that area. The hot and dry climatic area of Rajasthan Ministry of New and Renewable Energy (MNRE) have identified Solar and wind energy as the two most potent alternatives for conventional energy sources.[13] These renewable sources can guide the long-term goal of the Government of India, i.e. 750 GWh, energy generation till 2025,[14] from renewable sources. This is vital for the commitment that India has made in the Paris Convention. So, especially for existing buildings, it's essential to explore all the measures through which renewable energy can be generated and used to fulfil the energy needs of the occupants of the building. By implanting renewable energy in the form of solar and wind energy systems, net-zero to net-positive energy buildings can become a reality in the Indian landscape in the near future. However, special care must be taken to select the building integrated wind turbine model as its efficiency depends on the cut-in speed. Wind atlas is generally used to estimate the average wind speed.

There is a gradual shift in the thinking of going from low-energy buildings to net-zero energy buildings (nZEB) to net-positive energy buildings and to create a net-positive building. The definition of a low-energy building is vague, and the primary energy demand for the building varies from country to country; for example, green buildings in central Europe are 65 kWh/m^2/year for residential and 100 kWh/m^2/year for office building, whereas the passive houses in Germany, Austria, Denmark have a limit of 120 kWh/m²/year of maximum primary energy consumption.[15] Different building types offer different potentials for being net-positive energy buildings. Generally, an NPEB could be the one that produces more energy than is needed, and the surplus energy can be exported to other buildings and systems, i.e., 'energy storage management or feeding the extra energy produced to the grid'.[6] Considering individual buildings in a neighbourhood as part of a larger system when surplus energy generation can be shared with the building that needs it or the surplus energy can be exported can increase the power generated through renewable components within the grid.[16] Griffith et al. (2007) identified four characteristics relevant to achieving the ZEB target, i.e., number of stories, plug and process loads, principal building activity, and location. By reducing energy consumption even further through energy saving and energy efficiency, NPEB can become a reality in today's Indian landscape.[17]

Library buildings in an institutional campus belong to the category of buildings in which energy consumption is relatively low as well as enigmatic. By virtue of their varied occupancy and complex functioning, it is challenging to estimate the energy consumption in library buildings and is specifically tricky if there is no individual energy sub-metering for the building.[5] So, to find out the electricity footprint of such buildings, it is necessary to conduct an energy audit.

For a state like Rajasthan, there are ample sunny hours available for solar energy generation, and with the reliability of the grid, grid-connected solar PV systems can be beneficial. The estimate provided by the ISRO solar-calculator[18] gives a production of 299.6 kWh/m²/year considering 20% efficiency and energy loss. This estimation is based on the day length at the Central University of Rajasthan with minimum and maximum day lengths of 9.69 and 14.31 hrs respectively. The integration of a building-integrated wind turbine system can boost the chances of creating net-positive energy buildings. This system can generate electricity even during the night and on cloudy days when solar PV cannot generate electricity.

In this paper, a library building was taken up to find the possibility of net-positive energy building. For checking the solar energy potential, PVsyst software is used. PVsyst and whole building energy simulation collectively can be used to find the likelihood of the low energy, i.e., net positive zero energy status of buildings. Thus, the resultant energy model of the building along with the integration of the wind system would be crucial in estimating the energy generation on site and devising methodologies for reducing energy consumption and will help in guiding the long-term energy policy of the universities and institutes.

This study uses a primary energy audit, reconnaissance survey, and expert opinion survey to create an energy consumption model of the library building devoid of energy sub-metering. The Central Library Building, Central University of Rajasthan, was chosen as a case study that involves a single-story construction.

Methodology

The connected load and the university library's occupancy profile were found through the reconnaissance and occupancy survey. The help of expert opinion was also taken up for giving their views and finalising the input variables needed to compute the library's electricity consumption. Separated electricity consumption was estimated for weekends, summer seasons, and winter seasons. The electricity consumption was then computed. ISRO solar calculator was used for initial energy generation through a photovoltaic system. After the collection of the data, it was fed into the PVsyst 7.4.8 software, which is used to construct a solar PV system for the library by taking available PV modules and inverter systems. A building-integrated wind turbine system was integrated with the model and collective energy potential was calculated. Finally, comparisons were drawn between energy consumption and energy generation to check whether the result was fulfilling the criteria for a net-positive energy building or not.

Case Study

The library of the Central University of Rajasthan was taken up as a case study. It is located in the SP-2 building, which is a semi-permanent structure created through a pre-fabricated construction technique. This SP-2 building has a university auditorium as well. The overall area of the library including the reading hall covers an area of around 1,365 sq. meter plinth area. Figure 1 presents the Google Earth image of the SP-2 building. It has a separate reading hall capacity of around 500 seating capacity. The library section has windows on the north and south walls, whereas the main entry is from the lobby located in the western direction. The library has a separate stack area for books, periodicals (current and bound volumes), theses, reference sections, and a computer laboratory. The library is in the form of a large hall space with low-height partitions. By virtue of this type of construction, the library is devoid of any skylight on the roof. The low window-to-floor area ratio affects the ingress of natural daylight in the building; hence the lighting load is more than other conventional library buildings with good daylight integration facilities. The reading hall shares a common partition wall with an auditorium on the eastern side.

Due to the design constraints of semi-permanent prefabricated structures, such as the large indoor height of the library floor, the air-conditioning tonnage predicted requirement is way more than other standard-height air-conditioned library buildings. However, the building functions on an adaptive thermal comfort model, thus the number of air-conditioned units in the library is actually less and hence the air-conditioned tonnage per square meter is lower than that of a typical air-conditioned space. The floor-to-floor height is around 20 feet which discourages the use of ceiling fans. The library has a pitched roof with a shallow angle which has helped to reduce the solar heat gain through the roof. Figure 2 presents the plan of the library building.

Figure 1.Google Image of SP-2 Building

The two sections of the library namely the main library hall and the reading hall have different occupancy hours and operating days. The main library hall is operational five days a week with 9:30 a.m. to 6:30 p.m. as occupational hours. The main hall is closed on Weekends, i.e., Saturday and Sunday. The reading hall runs on all seven days of the week from 8:00 a.m. to 12:00 a.m. In the main library hall, there are 28 computers, out of which 10 are used by library staff, and the rest are used by students in the computer lab. There are three laser printers, one photocopy machine, there are ten split air conditioning units along with nine pedestrian fans to achieve thermal comfort in the summers. In winter five heaters are used in the library. There are 65 tube lights in the library's main hall. The connected load is 46150 W.

The reading hall has a connected load of 17300 W, which makes the total connected load of the library 63.45 kW. Around 60 to 70 persons are present in the reading hall per hour with a maximum occupancy of 100 to 120 in general, however, during examination days, it may go beyond 250 persons. The occupancy survey revealed that the yearly energy consumption is 322.49 MW which yields an energy performance ratio (EPI) of 236.25 kWh/m^2/year. If we consider the per-unit cost of electricity as Rs. 7.50 per unit, then the yearly electricity bill of the library building would be around 37.73 lacs.

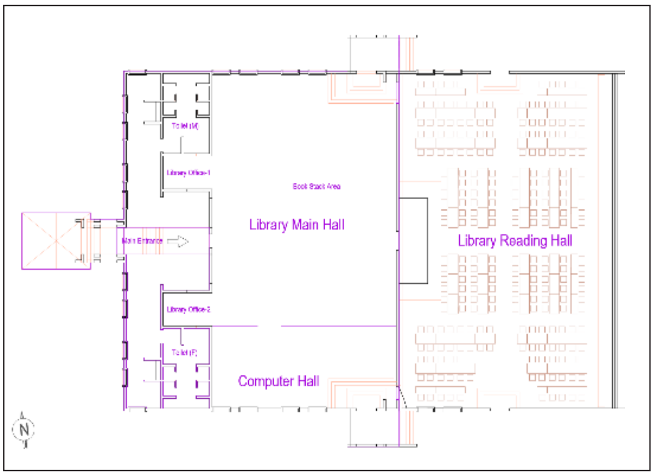

Figure 2.Plan of Central Library of Central University of Rajasthan

Result

The connected load of the library was found through a reconnaissance survey and is 189.45 kW. The survey yielded the types of electrical appliances used, their quantity, occupational time duration of users, etc. The survey included data like inventory prepared for types of electrical appliances used and their quantity. Expert opinion was also taken into account while estimating equipment usage. It was also found that the library runs almost 350 days in a year but has variable occupancy levels during weekdays, weekends, and during summer and winter holidays and Diwali holidays. The study room was used by 250 students daily. So, the energy consumption profile was divided into various parts, namely, summer-weekdays, summer-weekends, winter-weekdays, winter weekends, summer and winter vacation time. Table 1 shows the load profile of the main library hall and reading hall. The footfall and the behavioural pattern were computed through occupancy surveys and expert opinion surveys. The Annexure (mentioned at the end of the article) provides the energy consumption profile and PVsyst software result of the library building.

The calculation yields the total yearly electricity consumption of 322.49 MWh per year, which comes out to be around Rs. 24.19 lakhs. The EPI comes out to be 236.25 kWh/sqm/annum.

Renewable Energy-PVsyst

For the study, an optimum solar system is designed after taking the probable roof area of the Library Building into consideration. The solar system is simulated with the help of PVsyst software. Table 2 provides the typical losses that occurred in PV connections as per NREL that are taken up for consideration of solar PV systems.

Table 1.Load Profile of Library Building

S. No.	Item	LOAD Profile		
		Quantity	Wattage	Total Connected Load (Watt)
1	Computer (staff)	10	150	1500
	Computer (lab)	18	150	2700
2	Laptop	3	50	150
3	Printer	3	300	900
4	Photocopy machine	1	900	900
5	Pedestrian fan	9	50	450
6	UPS	1	16000	16000
7	Light	65	20	1300
8	Laptop for seating capacity (150), 1:5	5	50	250
9	AC	10	5000	50000
10	Miscellaneous	1	2000	2000
11	Heater	5	1000	5000
	Total-1 (main library hall)			81150
12	Light	45	20	900
13	Laptop	20	50	1000
14	AC	14	5000	70000
15	Total-2 (reading hall)			71900
16	Grand total			153050

Table 2.Expected energy loss assumptions for the PV system based on NREL[19]

S. No.	Losses	Loss Fraction (Percentage)
2.	Soiling	2.00
3.	Shading	3.00
4.	Snow	0.00
5.	Mismatch	2.00
6.	Wiring	2.00
7.	Connections	0.50
8.	Light-induced degradation	1.50
9.	Nameplate rating	1.00
10.	Age	0.00
11.	Availability	3.00
12.	Estimated system losses	14.08

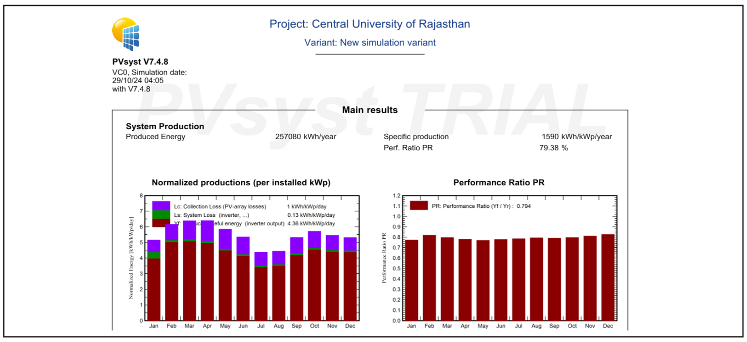

Figure 3.Main Results

Balances and main results	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray kWh	E_Grid kWh	PR ratio
January	114.6	43.5	15.19	159.9	149.9	22080	20015	0.774
February	134.4	45.4	19.21	172.5	162.6	23415	22872	0.820
March	173.7	63.3	25.58	198.0	185.9	26118	25515	0.797
April	190.7	77.6	30.44	191.8	179.2	24811	24228	0.781
May	198.2	90.3	34.26	181.5	168.6	23122	22579	0.769
June	180.0	100.6	33.02	160.5	148.2	20656	20171	0.777
July	150.7	93.7	30.25	135.8	124.8	17695	17256	0.786
August	144.2	89.0	28.64	137.8	127.1	18131	17683	0.793
September	150.6	74.7	28.69	159.6	148.6	20924	20432	0.792
October	147.2	65.9	27.50	177.1	166.1	23367	22833	0.797
November	120.0	44.2	21.81	163.7	153.6	21979	21474	0.811
December	112.8	37.6	17.04	164.8	154.7	22542	22022	0.826
Year	1817.2	825.8	26.00	2003.0	1869.2	264841	257080	0.794

Legends

GlobHor	Global horizontal irradiation	EArray	Effective energy at the output of the array
DiffHor	Horizontal diffuse irradiation	E_Grid	Energy injected into grid
T_Amb	Ambient Temperature	PR	Performance Ratio
GlobInc	Global incident in coll. plane		
GlobEff	Effective Global, corr. for IAM and shadings		

Table 3.Balances and Main Results Generated for the PVsyst Software

For this study, a 700 W_p Generic PV module was selected due to its relatively high energy yield. Since the focus is to create net-positive energy building, higher efficiency solar modules were considered. A total of 231 units were used in the system with a combined capacity of 162$kW_{p.}$ For the inverter, again a generic model was selected for the study and its number was chosen in accordance with the desired voltage and current requirement and need of the solar system. A total of 11 inverters of 12 kW were found suitable. The appropriate solar array and inverter were found after conducting numerous iterations with the help of PVsyst software. Simulation results showed that 257.08 MWh/year of electricity can be generated by a 720 sq. meter square PV installation covering 50% of the roof of the library section of the SP-2 building. This electricity generated by a solar PV system was similar to the energy requirement found in the total electricity consumption of the library building. The main results are displayed in Figure 3, whereas Table 3 provides the balances and main results generated for the PVsyst software. The main result provides a graphical representation of the normalised energy production and performance ratio of the solar system.

Building Integrated Wind Turbine System

The building-integrated wind turbine system used for the study has a cut-in speed of 3 m/s as the mean wind speed at the Central University of Rajasthan is 3.04 m/s at a 10-meter height. This product has a similar configuration as that of a product from a company windside. It can be quite handy during the monsoon season when solar availability is restricted due to high cloud cover and overcast conditions. The energy generation from this system having 10 turbines with a power of 500 W and efficiency of 40% can easily generate 17.50 MWh/annum and accounts for around 7.5% of the total energy consumption of the library. Here, only building integrated micro wind turbines are considered for the study. The cutting-edge technology for solar-wind hybrid energy systems provides a reliable, resilient, portable and modular system. So, the wind turbine can generate around 95 units of electricity each day, and it will be quite handy during the monsoon and months having a high cloudy cover when solar energy cannot be used efficiently.

Combined Energy Generation

So, the solar wind hybrid system can generate 270.58 MWh of energy per year which is more than the energy requirement of the complete library building including the main hall and reading hall.

Discussion

Implementation of the solar PV system and integrating it with a building-integrated wind turbine system can help to provide a continuous electricity supply to the library building. The excess amount of electricity can be given back to the GRID or can be used in other activities of the university. The climate of the Bander Sindri village area resembling the conflux of hot and dry and composite climate having good sunny hours throughout the year provides ample support to the hypothesis, i.e., going for the solar PV system. The building-integrated wind turbine used here for study has a low cut-in speed, which can be used in the university. Given regular maintenance, this hybrid-energy system can provide energy at least for 25 years, which is also considered the minimum age of the semi-permanent structure of the library by university authorities. The energy-saving potential within the building is needed for quantification through periodic energy audits. So, studies can be done related to energy audits of the library building so as to check the applicability of different energy efficiency measures which in turn will help in attaining net-positive energy building goals.

Conclusion

The net-positive energy building concept drives to link energy efficiency, energy-saving, and the use of renewable energy generation to achieve sustainable development goals. NPEB target is a difficult target to achieve, but the study showed that it can be achieved for a government university library building having a low energy performance index. The energy demand of library buildings is highly variable, so looking at this scenario, the solar PV system can be an effective strategy to mitigate this demand. Further, building-integrated wind turbines can be used along with solar PV systems to fulfil the energy demand when the sun is not available. So, A solar wind hybrid system can be more effective in creating NPEB instead of going up for a single power generation strategy where grid availability is missing. This hybrid system provides institutional buildings (library buildings) with a clean, affordable, and continuous renewable energy generation option. However, with the invention of a high-efficiency PV system, now it is possible to have NPEB solely on the basis of solar PV systems for low-EPI library buildings or similar university buildings located in government universities/ institutes. Further, integrating cutting-edge technology into the library building and conducting periodic energy audits can pave a pathway for fulfilling the goals related to the net positive energy library building where a substantial amount of electricity can be returned to the grid. Finally, these library buildings, by virtue of their nature and typology of building, could aid in information dissemination related to NPEB and sustainable practices to nearby communities.

Authors' Contribution

The authors' contributes by addressing the energy challenges in library buildings through innovative strategies like solar PV system and building-integrated wind turbine. Using PVsyst software, the study designs an optimal solar system, and incorporates hybrid energy systems to meet variable energy demands. The authors' collected the data related to equipment power density, library footfall, building architectural data, HVAC data, etc., of the library building and modeled it on PVsyst software. These efforts align with the lines of net positive energy goals for library building.

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Annexure

Table 4.Energy Consumption Profile and PVsyst Software Result

S. No.	Item	LOAD Profile			Summer Use		Summer Vacation Use			Winter Use		Winter Vacation Use			Weekends Use			Gazetted Holiday Use			Deepawali Vacation Use		
		Quantity	Wattage	Total connected Load (Watt)	Hours	Total Watt-hr.	Quantity	Hours	Total Watt-hr.	Winter Use Hrs.	Total Watt-hr.	Quantity	Hours	Total Watt-hr.	Quantity	Hours	Total Watt-hr.	Quantity	Hours	Total Watt-hr.	Quantity	Hours	Total Watt-hr.
1	Computer (Staff)	10	150	1500	8	12000	8	8	9600	8	12000	8	8	9600	10	0	0	10	0	0	8	8	9600
	Computer (Lab)	18	150	2700	9	24300	2	9	2700	10	27000	2	9	2700	18	0	0	18	0	0	2	9	2700
2	Laptop	3	50	150	2	300	1	2	100	2	300	1	2	100	3	0	0	3	0	0	1	2	100
3	Printer	3	300	900	2	1800	1	2	600	2	1800	1	2	600	3	0	0	3	0	0	1	2	600
4	Photocopy machine	1	900	900	1	900	1	1	900	1	900	1	1	900	1	0	0	1	0	0	1	1	900
5	Pedestrian Fan	9	50	450	8	3600	5	8	2000	0	0	5	8	2000	9	0	0	9	0	0	5	8	2000
6	UPS	1	16000	16000	0.25	4000	0.25	0.25	1000	0.25	4000	0.25	0.25	1000	1	0	0	1	0	0	0.25	0.25	1000
7	Light	65	20	1300	14.5	18850	9	14.5	2610	14.5	18850	9	14.5	2610	65	0	0	65	0	0	9	14.5	2610
8	Laptop for Seating capacity (150), 1:5	5	50	250	5	1250	2	5	500	5	1250	2	5	500	5	0	0	5	0	0	2	5	500
9	AC	10	5000	50000	9	450000	5	9	225000	0	0	0	9	0	10	0	0	10	0	0	5	9	225000
10	Miscellaneous	1	2000	2000	1	2000	1	1	2000	1	2000	1	1	2000	1	0	0	1	0	0	1	1	2000
11	Heater	5	1000	5000	0	0	0	0	0	9	45000	5	0	0	5	0	0	5	0	0	0	0	0
	Total			81150		519000			247010		113100			22010			0			0			247010
12	Light	45	20	900	16	14400	30	16	9600	16	14400	30	16	9600	45	16	14400	45	0	0	30	16	9600
13	Laptop	20	50	1000	10	10000	10	10	5000	10	10000	10	10	5000	20	10	10000	20	0	0	5	10	2500

14	AC	14	5000	70000	16	1120000	8	16	640000	0	0	0	16	0	10	8	400000	14	0	0	0	16	0
15	Total	-	-	71900	16	1144400	-	-	654600	0	24400	-		14600	-		424400	-		0	-		12100
16	Grand Total			153050	-	1663400			901610	-	137500			36610			424400			0			259110
17	Grand Total (kWh)			-		1663.4			901.61		137.5			36.61			424.4			0			259.11
18	Days					140			50		65			10			83			10			7
19	Total Energy Consumption (kWh)					232876.00			45080.50		8937.50			366.10			35225.20			0.00			1813.77
20	EPI/day					1.2186			0.6605		0.1007			0.0268			0.3109			0.0000			0.1898
21	Yearly Energy Use (KWh/or Units)			322485.30	322.49	-			-		-			-			-			-			-
22	Area of the Building			1365	-																		
23	EPI			236.25																			
24	EPI/Day			0.6473																			
25	Daily Energy Use (KWh/or Units)			883.52																			

Project: Central University of Rajasthan

Variant: New simulation variant

PVsyst V7.4.8
VC0, Simulation date:
29/10/24 04:05
with V7.4.8

General parameters

Grid-Connected System | **Sheds, single array**

PV Field Orientation

Orientation		**Sheds configuration**		**Models used**	
Fixed plane		Nb. of sheds	4 units	Transposition	Perez
Tilt/Azimuth	30 / 0 °	Single array		Diffuse	Perez, Meteonorm
		Sizes		Circumsolar	separate
		Sheds spacing	5.00 m		
		Collector width	2.63 m		
		Ground Cov. Ratio (GCR)	52.5 %		
		Top inactive band	0.02 m		
		Bottom inactive band	0.02 m		
		Shading limit angle			
		Limit profile angle	26.0 °		

Horizon	**Near Shadings**	**User's needs**
Free Horizon	Linear shadings : Fast (table)	Unlimited load (grid)

PV Array Characteristics

PV module		**Inverter**	
Manufacturer	Generic	Manufacturer	Generic
Model	Mono 700 Wp Twin half-cells bifacial	Model	12 kWac inverter
(Original PVsyst database)		(Original PVsyst database)	
Unit Nom. Power	700 Wp	Unit Nom. Power	12.0 kWac
Number of PV modules	231 units	Number of inverters	11 units
Nominal (STC)	162 kWp	Total power	132 kWac
Modules	21 string x 11 In series	Operating voltage	350-600 V
At operating cond. (50°C)		Max. power (=>25°C)	14.0 kWac
Pmpp	148 kWp	Pnom ratio (DC:AC)	1.22
U mpp	424 V		
I mpp	349 A		

Total PV power		**Total inverter power**	
Nominal (STC)	162 kWp	Total power	132 kWac
Total	231 modules	Max. power	154 kWac
Module area	718 m²	Number of inverters	11 units
Cell area	672 m²	Pnom ratio	1.22

Figure 4.General parameters and PV array Characteristics of solar PV system