



Net-Zero Energy Building Using Solar Photovoltaic Energy and Modeling within BIM Environment: Case Study of Al-Ajraf Elementary School in Quneitra

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Abstract

This research focuses on transforming Al-Ojraf Primary School in Quneitra Governorate into a zero-energy building by securing its energy source using a photovoltaic solar system. The Building Information Modeling (BIM) environment was utilized to create the necessary electrical plans and determine the available surface areas required for implementing this system. The existing electrical loads in the school (for lighting and fans) were initially calculated, followed by determining the suitable photovoltaic system to meet these loads, including the number of solar panels and the surface area needed for their installation. The calculated capacity of this system amounted to 12.510 kilowatts, composed of 12 solar panels, requiring an installation area of 32 square meters. The required capacity of the photovoltaic system was recalculated after replacing the school's electrical equipment with devices operating on direct current (DC), resulting in a system capacity of 7.260 kilowatts, providing a savings of 5.25 kilowatts, i.e., by 42%. The number of panels required to power the school's loads decreased to 6 panels, reducing the necessary installation area to 16 square meters, i.e., by 50%. This replacement also eliminated the need for batteries and expensive inverters, resulting in significant cost savings and a substantial reduction in electricity consumption from the main grid. In Sweida Governorate there are a total of 253 elementary schools. If these schools were transformed into zero-energy buildings following the method outlined in this research, it would lead to a daily saving of 1328.25 kilowatts from the main grid.

Keywords: Net zero energy building; building information modeling; photovoltaic; direct current devices; direct current loads.

1.0 Introduction

The demand for energy is increasing significantly due to the spread of heavy industries, transformational industries, investments, and other sectors [1]. These industries mostly rely on fossil fuels, which are the main cause of global warming [2] due to the large amounts of carbon dioxide (CO₂) emissions and the significant environmental damage caused by their exploration, extraction, and refining. Consequently, there has been a recent shift towards producing electricity from environmentally friendly renewable sources [3], which do not produce any greenhouse gas emissions

during energy generation [4]. Solar photovoltaic and wind energy are considered among the most important and widely distributed renewable energy sources worldwide [5] [6]. Recently, there has been an effort to develop microgrid electrical networks that include their own electricity sources, often from renewable sources [7]. These microgrids are capable of producing the required electricity for connected loads, which could be several buildings or small villages located far from the main grid [8] [6].

From this concept, the concept of Net Zero Energy Buildings (NZEB) [9] emerged and has become widespread. NZEBs can secure the required amounts of energy through reliance on renewable sources in a way that their total energy consumption over a specific period equals zero [10]. Additionally, NZEBs have negligible CO₂ emissions [11] [12]. It is worth mentioning that the creation of such buildings was driven by the need to implement environmental standards to address critical environmental issues [13] [14].

Accompanying the emergence of NZEBs is the trend towards using loads or devices that operate on Direct Current (DC) [15]. The goal is to utilize renewable energy sources that produce direct current without the need for conversion to Alternating Current (AC) at a specific frequency using inverters. This transformation process has several advantages, such as lower material costs for direct current devices, reduced susceptibility to malfunctions, and longer operational lifespan compared to AC devices [16].

In this context, Building Information Modeling (BIM) [17] [18] is considered an essential tool to achieve these goals [19] [20]. It enables the design and construction of a three-dimensional model that provides better visualization [21], detects potential clashes, facilitates collaboration and communication, estimates cost, improves sustainability and continuity [22], and enhances construction quality [23] [24].

Many countries around the world have adopted BIM technology [25] [26]. The United States is believed to be one of the leading countries in adopting BIM models [27]. Many public sector bodies at different levels in the United States have established BIM programs [28], set up BIM goals and Application roadmaps, and published BIM standards [29] [30]. In 2008, for example, the United States National Institute for Building Sciences (NIBS) published the National Building Information Modeling Standard (NBIMS-USTM). Apart from the United States, many countries in Europe have embarked on significant BIM Applications [31]. The United Kingdom government, for example, mandated that all UK government projects should use BIM by 2016 [32].

Barriers to BIM implementation in one country are different from other countries [33] [34]. This is because each country sees the obstacles from various perspectives based on the country's own background [35]. Lack of regulations in countries contributes to the unfamiliarity of BIM implementation [36]. Support and direction from the government, as well as the mandatory use of BIM in projects, will improve the implementation of BIM [37].

2.0 Literature Review:

Several studies have demonstrated the results of using BIM to achieve Net Zero Energy Buildings (NZEBs). In Turkey, a BIM model was created for six buildings that rely on renewable energy as a source of electricity, using Autodesk Revit, with the aim of achieving NZEBs [38]. The study revealed numerous benefits of using BIM in these projects, such as reducing errors, expediting and improving efficiency of processes, increasing productivity, minimizing uncertainties, controlling project lifecycle, and conducting energy analyses during the design phase [39].

Similarly, a study was conducted in Iraq, where Building Information Modeling (BIM) was used as a design tool for residential units and achieving Net Zero Energy Buildings by enhancing the design of existing buildings [40]. The integrated Photovoltaic Thermal (PV/T) building produced approximately 37% of the required energy, representing a significant portion of the overall energy savings for the residential building. Moreover, the increased demand for renewable energy sources in buildings is

expected to have a positive environmental impact, reducing carbon dioxide emissions, and achieving a self-sufficient and energy-efficient building in line with the concept of NZEB [41].

Within this study, the size of the solar system was calculated using the following equations:

$$\text{Battery Bank Capacity} = \frac{\text{Total Consumed Energy in (Wh)} \times \text{Number of Backup Days}}{\text{System Voltage in (V)} \times \text{System Efficiency} \times \text{Depth of Discharge}}$$

Battery bank capacity is defined as the amount of charge stored by batteries and is measured in ampere-hours (Ah).

The system efficiency, on the other hand, is the quantity of solar energy that can be converted into electricity using photovoltaic solar cells.

$$\text{Number of Batteries} = \frac{\text{Battery Bank Capacity (Ah)}}{\text{Capacity of One Battery (Ah)}}$$

The number of solar panels is calculated as follows:

$$\text{Number of Solar Panels} = \frac{\text{Total Daily Required Energy (Wh)}}{\text{Solar Radiation Hours (h)} \times \text{System Efficiency} \times \text{Capacity of One Solar Panel (V)}}$$

Solar radiation, also known as solar irradiance or solar insolation, is the amount of solar rays received per specific area capable of generating electrical power.

3.0 Research Method

In this study, Al-Ojraf Elementary School in Al-Quneitra Governorate was chosen as the case study for its conversion into a Net Zero Energy Building (NZEB). This was achieved by providing a solar photovoltaic system to serve as the energy source. The necessary electrical plans were developed using Building Information Modeling (BIM) environment, while architectural and structural models of the school were created using Revit 2020 software. To minimize energy consumption in the building, direct current (DC) equipment was used for lighting and fans instead of alternating current (AC) equipment. The findings were generalized to be applicable to all primary schools in As-Suwayda Governorate, aiming to identify potential savings.

4.0 Case Study

4.1 Building Description

The subject of this study is Al-Ojraf Elementary School, located in Al-Quneitra Governorate, Syria. This educational building is under the supervision of the Syrian Ministry of Education and consists of a single-story ground floor. It comprises seven classrooms, one administrative room, and three utility rooms. The school is divided into two sections, one with a northeast-facing facade and the other with a southwest-facing facade. Figure (1) presents an image taken from Google Maps, illustrating the location of Al-Ojraf Elementary School.

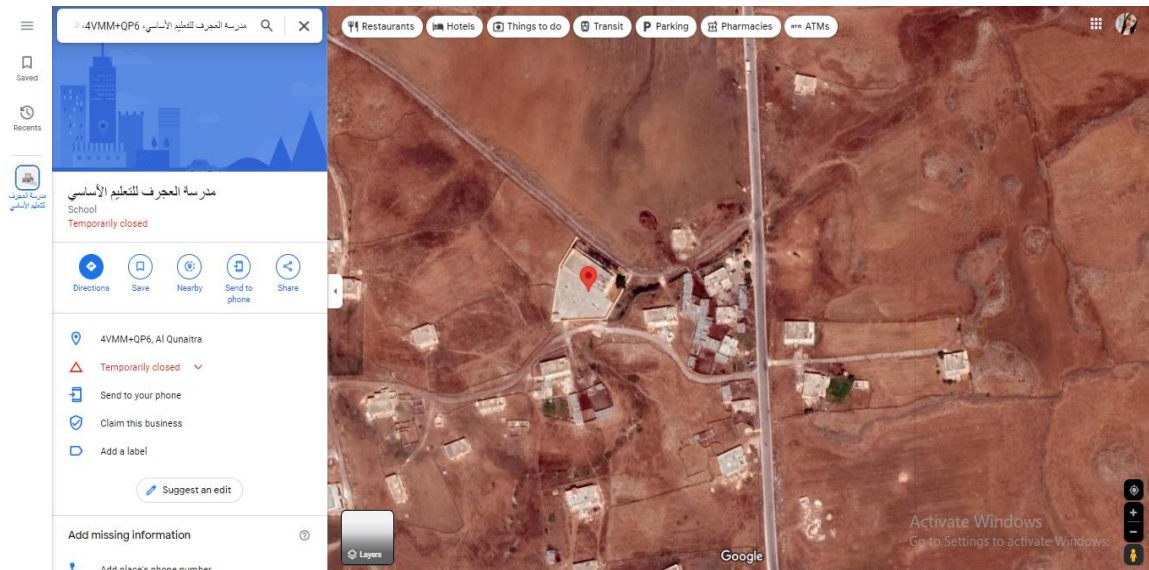


Figure 1: A snapshot from Google Maps showing the location of Al-Ojraf Elementary School for Basic Education.

The selection of this school was based on the following reasons:

- It is a typical educational building similar to the prevailing design of elementary schools in Syria.
- The school needs renovation.
- Sufficient information is available about this school, including architectural and structural models within the Revit environment.
- It is the only school in Al-Ojraf village and the closest elementary school, located more than 5 km away due to the absence of public transportation.

Table (1) illustrates the distribution, use, and orientations of the rooms:

Table 1: Distribution, Use, and Orientations of the Rooms

Room Use	Room Orientation	Room Area (square meters)
Principal's Office	Northeast	17
Classroom 1	Southwest	35
Classroom 2	Southwest	33
Classroom 3	Northeast	33
Classroom 4	Southwest	35
Classroom 5	Northeast	35
Classroom 6	Northeast	33
Classroom 7	Southwest	35
Hallway 1	Southwest	36
Hallway 2	Southwest	100
Bathroom 1	Northeast	17
Bathroom 2	Northeast	10
Bathroom 3	Northeast	21

1.1 Practical Study:

Calculating the total photovoltaic capacity required to power the essential loads in the school under the current conditions:

Energy consumption in schools generally occurs during daylight hours, typically from 8:00 AM to 12:00 PM, according to official school hours. We will calculate the total photovoltaic capacity needed to operate the essential loads in Al-Ojraf Elementary School under its current situation, i.e., before replacing its existing electrical appliances.

Table (2) shows the existing loads in the school:

Table (2): Current Loads in the School

Load Type	Total Power (Watt)
Lighting	2260
Outlets	4750
Mechanical Loads	5100
Total Power Consumption	12510

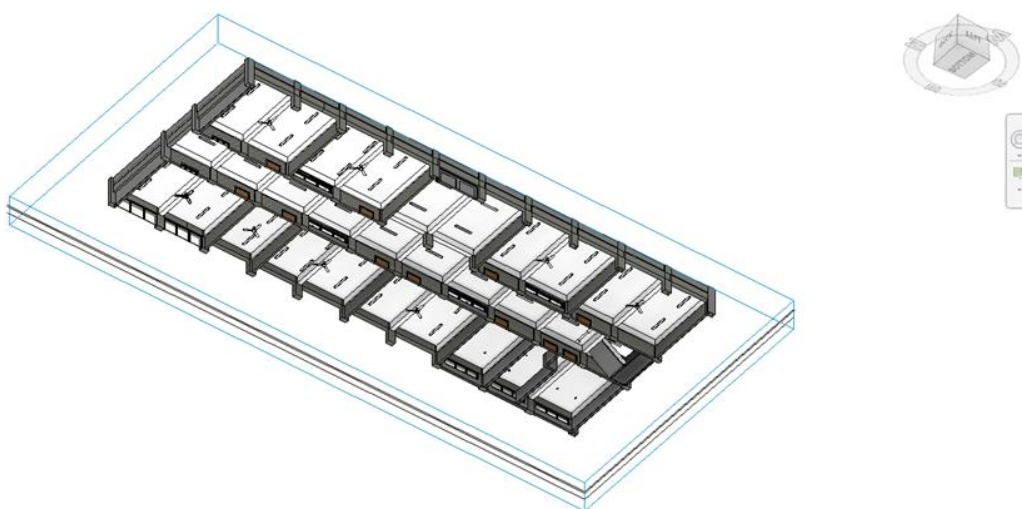


Figure 2: A snapshot from Revit software illustrating the current electrical equipment of the school.

- Calculating the Total Photovoltaic Capacity Required to Power the Essential Loads in the School after Replacing Electrical Appliances:

The lighting and mechanical appliances that previously operated on alternating current (AC) were replaced with ones that run on direct current (DC), while the outlets remained unchanged. Table (3) presents the loads in the school after replacing the electrical appliances:

Table 3: Loads in the School after Replacing Electrical Appliances

Total Power (Watt)	Load Type
1810	Lighting
4750	Outlets
700	Mechanical Loads
7260	Total Power Consumption

- Calculating the Size of the Photovoltaic Solar System in the Current situation:

Now, we will calculate the required size of the photovoltaic solar system, including the number and capacity of batteries, the number and capacity of the solar panels, and the required capacity of the inverter to operate the loads in the current situation. Table (4) presents the details:

Table 4: Required Size of the Photovoltaic Solar System in the Current situation

Load Type	Quantity	Electrical Capacity (W)	Daily Operating Hours	Required Energy (Wh)
Lighting	1	2660	4	10640
Outlets	1	2000	2	4000
Computers	2	2000	4	8000
Printer	1	250	4	1000
Projector	1	500	4	2000
Fan	1	4800	4	19200
Extractor Fan	1	300	4	1200
		12510	Total Power	46040

Calculating the Battery Bank Capacity:

Assuming the use of a lithium battery with a capacity of 200 ampere-hours (Ah) at 48 volts, the battery bank capacity is determined as follows:

$$\text{Battery Bank Capacity} = \frac{\text{Total Consumed Energy in (Wh)} \times \text{Number of Backup Days}}{\text{System Voltage in (V)} \times \text{System Efficiency} \times \text{Depth of Discharge}}$$

$$\text{Battery Bank Capacity} = \frac{246040\text{Wh} \times 1 \text{ day}}{48\text{V} \times 0.93 \times 0.8} = 1290\text{Ah}$$

Battery capacity per unit is 200 ampere-hours, thus:

$$\text{Number of Batteries} = \frac{\text{Battery Bank Capacity (Ah)}}{\text{Capacity of One Battery (Ah)}}$$

$$\text{Number of Batteries} = \frac{1290\text{Ah}}{200\text{Ah}} = 6 \text{ Batteries}$$

Calculating the Number of Solar Panels:

$$\text{Number of Solar Panels} = \frac{\text{Total Daily Required Energy (Wh)}}{\text{Solar Radiation Hours (h)} \times \text{System Efficiency} \times \text{Capacity of One Solar Panel (V)}}$$

$$\text{Number of Solar Panels} = \frac{46040}{8 \times 0.93 \times 550} = 12 \text{ Panels}$$

Assuming the selection of LONGI solar panels with a capacity of 550W, the total photovoltaic capacity would be:

$$\text{Total Solar Panel Capacity} = 12 \times 550 = 6600\text{W}$$

Inverter Selection:

The required electrical capacity is 12510W. We choose an inverter with a capacity of 30% more, thus it would be:

$$\text{Required Electrical Capacity} = 12510 \times 1.3 = 16263\text{W}$$

Therefore, we select an inverter with a capacity of 20 kilowatts.

- Calculation of the Photovoltaic System Size after replacing the current AC-powered equipment with DC-powered ones:

Now, we will calculate the required size of the photovoltaic system, including the number and capacity of batteries, the number of required solar panels, and the capacity of the inverter, considering the replacement of the current AC-powered equipment with DC-powered ones. Table (5) presents the details:

Table 5: Photovoltaic System Size after replacing the current AC-powered equipment with DC-powered one

Load Type	Quantity	Electrical Capacity (W)	Daily Operating Hours	Required Energy (Wh)
Lighting	1	1810	4	7,240
Outlets	1	2000	2	4000
Computers	2	2000	4	8,000
Printer	1	250	4	1000
Projector	1	500	4	2,000
Fan	1	400	4	1600
Extractor Fan	1	300	4	1,200
		7260	Total Power	25,040

Battery Bank Capacity:

Assuming the use of lithium batteries with a capacity of 200 ampere-hours and 48 volts, the calculation for the battery bank capacity would be as follows:

Each battery has a capacity of 200 ampere-hours, so the battery bank capacity can be calculated as follows:

$$\text{Battery Bank Capacity} = \frac{\text{Total Consumed Energy in (Wh)} \times \text{Number of Backup Days}}{\text{System Voltage in (V)} \times \text{System Efficiency} \times \text{Depth of Discharge}}$$

$$\text{Battery Bank Capacity} = \frac{225040\text{Wh} \times 1 \text{ day}}{48\text{V} \times 0.93 \times 0.8} = 701\text{Ah}$$

Battery capacity per unit is 200 ampere-hours, thus:

$$\text{Number of Batteries} = \frac{\text{Battery Bank Capacity (Ah)}}{\text{Capacity of One Battery (Ah)}}$$

$$\text{Number of Batteries} = \frac{701\text{Ah}}{200\text{Ah}} = 4 \text{ Batteries}$$

Calculating the Number of Solar Panels:

$$\begin{aligned} & \text{Number of Solar Panels} \\ &= \frac{\text{Total Daily Required Energy (Wh)}}{\text{Solar Radiation Hours (h) x System Efficiency x Capacity of One Solar Panel (V)}} \end{aligned}$$

$$\text{Number of Solar Panels} = \frac{25040}{8 \times 0.93 \times 550} = 6 \text{ Panels}$$

Assuming the selection of LONGI solar panels with a capacity of 550W, the total photovoltaic capacity would be:

$$\text{Total Solar Panel Capacity} = 6 \times 550 = \text{W}3300$$

Inverter Selection:

The required electrical capacity is 7260W. We choose an inverter with a capacity of 30% more, thus it would be:

$$\text{Required Electrical Capacity} = 7260 \times 1.3 = 9483\text{W}$$

Therefore, we select an inverter with a capacity of 10 kilowatts.

- Comparison between the First and Second Scenarios for the Solar Photovoltaic System:
 - A. Comparison of Electrical Equipment:

Table (6) shows a comparison between the required photovoltaic equipment for AC-powered loads and DC-powered loads:

Table 6: Comparison between the required photovoltaic equipment for AC-powered loads and DC-powered loads

		AC Loads	DC Loads
Solar Panels	Number	12	6
	Power (KW)	6.6	3.3
Batteries	Number	6	4

	Capacity (Ah)	1290	701
Inverter	Power (KW)	20	10

From Table (6), we notice a decrease in the number of required photovoltaic panels by half and a 30% decrease in the number of batteries when switching from AC-powered to DC-powered loads. The required number of inverters also reduced by half. These changes significantly impact the overall cost of the required solar photovoltaic system.

B. Comparison of Area:

Longi solar panels with a capacity of 550W and dimensions (H/W/D) 2278/1134/35 mm were used. The panels were installed at an angle of 30 degrees from the south, as shown in Figure (3).

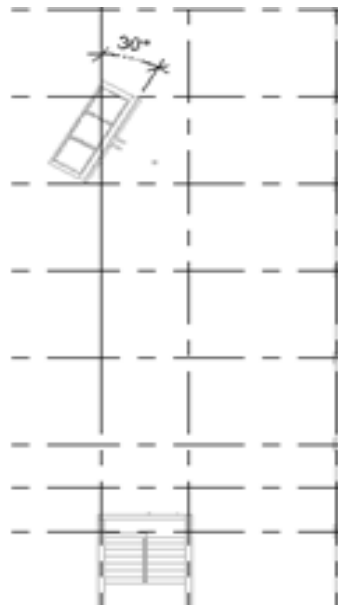


Figure 3: A snapshot from the Revit software showing the angle of installation for the solar panels.

Table (7) illustrates the required area for installing the solar panels at the school in its current state and after replacing the existing AC-powered devices with DC-powered ones.

Table 7: The required area for installing solar panels at the school in its current state and after replacing the existing devices with DC-powered ones

	AC Loads	DC Loads
Required Area for Solar Panel Installation (m ²)	32	16

From the above table, it can be observed that 50% of the surface area required for solar panel installation is saved when replacing the existing devices. Figure (4) presents a snapshot from the Revit software showing the placement of solar panels on the school's surface in both scenarios.

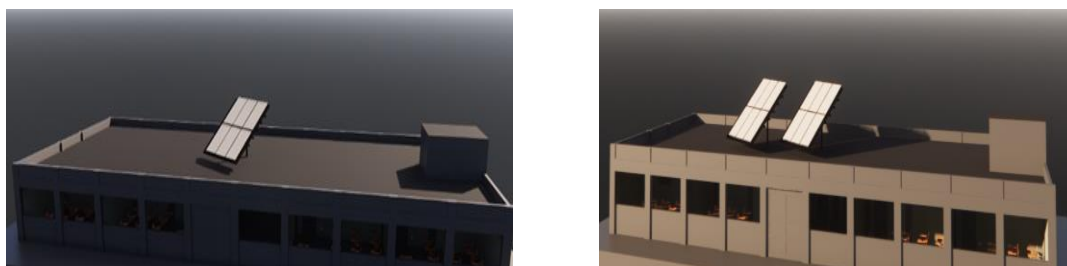


Figure 4: A snapshot from Revit software showing the placement of solar panels on the school's surface in both scenarios.

C. Economic Comparison:

Table (8) shows the prices of the existing AC-powered electrical equipment currently installed at Al-Ojraf Elementary School:

Table 8: Prices of the existing AC-powered electrical equipment at Al-Ojraf Elementary School

Item	Quantity	Unit Price (SYP)	Total Price (SYP)
40W Fluorescent Lighting Fixture	60	50,000	3,000,000
20W Spot Lighting Fixture	13	65,000	845,000
600W Fan	8	375,000	3,000,000
Solar Panels	12	2,000,000	24,000,000
Lithium Battery	6	15,000,000	90,000,000
20kW Inverter	1	25,000,000	25,000,000
Metal Mounting Structure for Solar Panels	1	500,000	6,000,000
Breakers, Protection, and Cables	-	-	3,000,000
		Total Price	154,845,000

Table (9) shows the prices of the DC-powered electrical equipment if the existing AC-powered devices were replaced:

Table 9: Prices of the DC-powered electrical equipment if the existing devices were replaced

Item	Quantity	Unit Price (SYP)	Total Price (SYP)
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W LED 28 Lighting Fixture	60	50,000	3,000,000
W LED 10 Spot Lighting Fixture	13	35,000	525,000
W Fan50	8	125,000	3,000,000
Solar Panels	6	2,000,000	12,000,000
Lithium Battery	4	15,000,000	60,000,000
kW 10 Inverter	1	15,000,000	15,000,000
Metal Mounting Structure for Solar Panels	1	500,000	3,000,000
Breakers, Protection, and Cables	-	-	3,000,000
		Total Price	99,525,000

By comparing the final values with the AC-powered devices, we note that operating the DC-powered devices achieves cost savings of 55,320,000 SYP, which is approximately 35.72%

When there is a need to operate the basic loads at the school relying on electricity from the main grid daily from 8:00 AM to 12:00 PM, the cost of one kilowatt-hour (kWh) of electricity during this time is 2.5 SYP according to the Syrian Electricity Investment System (Attachment 5). Thus, the daily consumption would be:

$$2.5 \times 46,040 = 115,100 \text{ SYP}$$

And the monthly consumption would be:

$$115,100 \times 30 = 3,453,000 \text{ SYP}$$

Based on this, applying the proposed solar photovoltaic system to all primary schools in the Sweida Governorate, which total 253 schools, would save 14 billion SYP and generate a savings of 1,328 megawatts from the main grid daily, equivalent to 29.22 megawatts monthly.

5.0 Results

1. The utilization of DC-powered electrical equipment led to a 42% reduction in the required capacity of the photovoltaic solar system, and a decrease of approximately 50% in the number of necessary equipment components.
2. The implementation of DC-powered devices resulted in a cost reduction of 35.72% compared to using AC-powered equipment.
3. The surface area needed for installing solar panels was halved.
4. The proposed approach in this study ensured a supply of 1.328 megawatts from the general grid on a daily basis, equivalent to 29.22 megawatts per month, for meeting the required electrical energy demand of all schools in Sweida Governorate.
5. The utilization of BIM modeling in the school's environment facilitated the calculation of various electrical loads and streamlined the process when transitioning to DC-powered equipment.

6. BIM modeling provided accurate placement and proper orientation of photovoltaic solar panels.

6.0 Discussion and Recommendations:

1. Conduct a similar study on government buildings located in areas far from the power grid.
2. Perform energy analysis on buildings using electrical modeling software during the design phase to obtain more accurate information.
3. Promote the culture of energy sustainability by adopting environmentally friendly renewable energy sources, especially solar photovoltaic energy, and integrating them into buildings.

7.0 Conclusion:

The study demonstrated that converting Al-Ojraf School in the Quneitra Governorate into a zero-energy building using DC-powered devices is a viable and sustainable investment in energy savings. By utilizing a solar photovoltaic system and BIM technology for electrical planning, energy consumption efficiency was improved, and costs were reduced. If this technology is applied to other schools in the Sweida Governorate, significant energy savings from the main grid would be achieved daily. Therefore, this study represents an important step toward developing schools for sustainability and environmental conservation. It is recommended to continue using BIM technology in planning and implementing projects to transform buildings into zero-energy structures.

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