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# Energy Auditing and Management with PV Rooftop Design at the Electrical Engineering Department of Assiut University, Egypt

**Mohammed Nayel [1], Amr Sayed Hassan Abdallah [2,*], Mahmoud Aref [1], Randa Mohamed Ahmed Mahmoud [3] and Mohamed Bechir Ben Hamida [4]**

[1] Electrical Engineering Department, Faculty of Engineering, Assiut University, Assiut 71516, Egypt; mohamed.nayel@aun.edu.eg (M.N.); mahmoud.aref@eng.aun.edu.eg (M.A.)
[2] Department of Architectural Engineering, College of Engineering, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh 11432, Saudi Arabia
[3] Department of Architecture, Faculty of Engineering, Assiut University, Assiut 71516, Egypt; randa.m@aun.edu.eg
[4] Deanship of Scientific Research, Imam Mohammad Ibn Saud Islamic University (IMSIU), Riyadh 11432, Saudi Arabia; MBHamida@imamu.edu.sa
* Correspondence: asabdullah@imamu.edu.sa

**Abstract**

Due to the high energy demand of buildings, especially educational buildings, it is crucial to improve total building energy consumption. The proposed methodology is the integration of a photovoltaic (PV) system with a smart control plan for educational buildings. The main aim is to improve energy consumption in an educational building (Electrical Engineering Department, Assiut University, Egypt) using photovoltaic integration and a smart control plan to regulate energy and boost indoor comfort without requiring a significant change in the building architecture. This study was conducted in two main phases: field measurements for annual energy consumption in Assiut University over a five-year period from 2009 to 2014, and an analysis of energy consumption for the Electrical Engineering Department. Then, integration of PV panels on the roof to generate electricity was considered, with the calculation of the shading factor and tilt angle to ensure a realistic estimation of energy yield and to improve energy efficiency using smart control plans. The findings indicate that the average annual peak consumption reached about 30 GWh in Assiut University during the academic years 2009 to 2014. The maximum energy consumption for a typical occupied day in the educational building is 47 kWh. An improvement in building energy consumption was achieved using PV, producing 33–35 MWh annually with an effective smart control plan and without installing sensor-based systems. The results of this study will help improve energy consumption for educational buildings in hot arid climates without building modifications. This study highlights that unoccupied periods—when human activity is absent in classrooms and other rooms—account for up to 40% of the scheduled energy consumption. Using PV panels will result in a shading factor of 0.562 from the total roof area.

**Keywords:** educational building; total energy consumption; smart system; photovoltaic

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## 1. Introduction

Over the past few years, energy consumption has increased significantly in public buildings worldwide. Hence, the need for energy-efficient approaches has increased [1].

University educational buildings represent an interesting sector for studying and evaluating the design and implementation of sustainability and energy efficiency guidelines [2], as educational buildings usually consume more energy [3]. It is important to note that the amount of energy consumed by an educational building depends mostly on the activities taking place in the building, its occupation schedule, and the number of scholars, staff, and professors [1,4]. The electrical loads in educational buildings, in hot areas, are divided into air conditioning systems, lighting systems and equipment [5]. Educational buildings are of specific concern because students spend up to 25% of their time indoors. Therefore, it is very important to create a comfortable microclimate within the building. The aim is to improve the use of natural resources in the building stock and formulate guidelines for the inclusion of parameters such as environmental impact, energy performance, and thermal comfort in the planning of new installations. The existing stock of institutional buildings, built prior to current temperature regulation, is known to consume a lot of energy. To save energy, retrofit solutions must deal with important transformations of these buildings and find better management solutions. Potential studies on campus energy include an energy audit process that provides information on the availability of energy efficiency resources on campus and allows for the development of cost-and-savings strategies. Campus energy potential research offers many of the same benefits as standard energy studies do, such as understanding how efficient campuses are in terms of energy use and planning projects to reduce energy consumption.

An energy audit is an important systematic inspection of power to measure the loss of energy in organizations. It is used to improve the practical operation of the organization system as well as improving efficiency and minimizing pollution. The audit process provides a significant database for full analysis of energy use by the organization, which is used for minimizing energy loss by managing input energy and predicting the amount of input energy for a good process via collecting previous data of energy consumption and production of the organization. A detailed examination of electrical power consumption and the cost of this power consumption for college premises (Vishwaniketan Institute) is presented in [6]. A program is suggested for changes to working practices or power-consuming equipment for effective cost savings. The audit method involves collecting data of a facility operation and recording service bills to calculate used and wasted energy in colleges. The authors of [7] provided an on-site measurement and dynamic modeling approach to energy modernization design by developing an energy model of a university building in the cold–moderate climate of the southern Italian region. The suggested method depends on solving a limited multi-purpose problem using a genetic algorithm implemented in Energy Plus. In the Ecuadorian Building Standard NEC-1 [8], the proposed method—for implementing a detailed energy audit as a tool for quantifying performance—is performed in four steps: visual inspection, data collection, electrical equipment measurement, interpretation of results, and analysis (described in Ref. [8]). The Engineering Laboratory of the Faculty was established to correct the proposed steps and test their ability to determine energy consumption and the types of electrical distribution devices and lamps. Estimates of monthly energy consumption were studied by analyzing the electricity bills in [9], indicating the energy-saving areas of the institute offering engineering programs.

To eliminate energy losses in the educational building of the Azerbaijan University of Architecture and Civil Engineering (AzUAC), a detailed multi-disciplinary energy audit was used to apply low-cost energy efficiency measures and monitor aspects of the building's lifecycle in terms of design, production of materials and their processing, operation, maintenance and re-equipment of buildings [10]. The concepts of energy auditing were adopted and applied to two buildings in the Engineering and Architecture School, the University of Passo Fundo–Southern Brazil, representing the different typologies of UPF

Campus I [11]. One of the energy audit methods is energy certification, which is used to improve energy efficiency measures and cost–benefit calculations. Certification started in 2012 at the University of Zagreb [12]. An energy efficiency plan for the Portuguese Higher Education Building-Faculty of Economics, University of Coimbra (FEUC), was proposed in [13], with technical and behavioral improvement measures through the development of learning in the context of Green Campus-Energy Efficiency Challenge in Higher Education and the Energy for Sustainability Initiative of the University of Coimbra, Portugal. An energy audit was carried out based on an analysis of energy consumption profiles; a monitoring campaign was carried out to measure and disaggregate electricity consumption. Natural gas and water consumption were also assessed, as well as building envelope, heating and lighting systems. The energy audit protocol was developed and implemented to simultaneously address the issues of thermal comfort and energy efficiency of buildings in higher education institutions [14]. An energy audit was conducted at Covenant University in Nigeria to look for ways to reduce energy costs. The university's total electricity demand for cooling and lighting is approximately the highest electricity consumption (29%) [15]. Comparative analysis of energy consumption was conducted for three higher education institutions located on the same campus in the region of Paris, France. These three buildings are used in a similar way, mainly for educational and research purposes. Hence, they were built in accordance with three different national energy regulations. The assessment of the impact of these regulations on the energy performance of buildings is studied through a global analysis of annual and monthly energy consumption and the use of statistical tools to characterize the dynamics of electricity demand [16]. Energy audits and internal environmental audits for energy consumption and indoor air quality were performed in 24 school buildings in Slovenia. Reviews show that these buildings are high energy consumers and have poor indoor air quality, as expressed by 60% of the students surveyed. The nominal heating power of boilers and heat exchangers, which are used for district heating, shows an increased capacity of 57% [17]. An Energy Audit Tool (PHPP) versus a Dynamic Simulator (TRNSYS) is used to evaluate energy conservation measures in a pilot case study. The overall comparison of useful heating and cooling requirements, and loads included three types of buildings (single-, multi-family house, and office), three energy levels and seven European climates. Dynamic simulation results prove that PHPP (Monthly Energy Balance) can calculate heating demand and energy savings with good accuracy, and cooling demand with acceptable accuracy compared to detailed digital models (TRNSYS). The quality of the thermosphere was higher. In addition, it was confirmed that PHPP slightly overestimated thermal and cooling loads when designing the system. This multi-family house renovation project was carried out using PHPP as an energy audit tool. Several computational steps were performed for (a) the baseline, (b) the design phase and (c) verification with monitoring to calculate the corresponding heat demand [18]. Energy audits in universities, such as at Arba Mincha Institute of Technology (AMIT) [19], mainly focus on identifying energy-wasting activities and proposing low-cost conservation measures. These studies typically assess lighting, office equipment, computers, and plumbing fixtures to improve operational efficiency. Similarly, the Polytechnic Institute of Leiria applied energy performance indices to classify buildings according to efficiency levels. However, these approaches remain largely descriptive and benchmarking-oriented. They do not integrate renewable energy systems such as photovoltaic generation with audit findings. Additionally, limited consideration is given to occupancy dynamics and academic schedules. Climate-responsive modeling, particularly for hot arid regions, is also underexplored. Therefore, a more integrated framework combining long-term audit data, operational control, and renewable energy strategies is still needed. The energy

savings potential was also estimated based on a building energy reference index for each classification, considering two different scenarios [20].

Although ECBCS Annex 36 and the Energy Concept Advisor (ECA) tool provide structured guidance for improving energy efficiency in educational buildings, their focus is primarily on early design-stage decision support and financial modernization strategies. These frameworks emphasize planning and benchmarking rather than post-occupancy performance validation. Limited attention is given to real operational data, behavioral variability, and dynamic load management. Moreover, integration with on-site renewable energy systems and climate-specific adaptation strategies remains underdeveloped. This reveals a gap between theoretical decision support tools and practical, performance-based energy management in existing educational buildings [21]. Although the UNAM study provides valuable projections of campus-wide energy use and greenhouse gas emissions through scenario analysis, it primarily relies on representative sampling and modeled mitigation pathways. The approach emphasizes future projections rather than detailed operational load behavior or real-time energy management within individual buildings. Consequently, the integration of measured performance data with practical, building-level renewable energy and control strategies remains insufficiently addressed [22]. While the Ukrainian framework offers a structured approach based on energy audits, certification, and ISO 9000 standards [23], it remains largely policy- and management-oriented. The model emphasizes institutional procedures rather than detailed building-level performance analysis or climate-responsive design adaptation. As a result, the practical integration of operational data, renewable energy systems, and smart control strategies in real university buildings is still insufficiently explored [23]. Although the studies at Taiba University and Pennsylvania State University provide structured audit procedures and software-based monitoring frameworks, they focus mainly on assessment and process validation rather than integrated energy reduction strategies. The approaches emphasize diagnostic evaluation but offer limited linkage to renewable energy integration or adaptive operational control. Consequently, the transition from energy auditing to practical, climate-responsive performance optimization remains insufficiently developed [24,25].

Today, the need for the university to be a leader in reducing greenhouse gas emissions has become a global concern. The power system was analyzed for a campus model in Southern China, and the energy consumption of the entire campus was studied in terms of reducing greenhouse gas emissions [26]. Although the implementation of BEMS and detailed audits, such as in the Hydrotechnical building-2 case, provide valuable monitoring of daily and hourly energy patterns, they mainly emphasize technological control systems. These approaches often rely on advanced infrastructure without examining cost-effective alternatives suitable for existing buildings with limited budgets. As a result, the integration of simplified operational strategies and climate-responsive renewable solutions remains insufficiently addressed [27]. Although the study at Shaqra University highlights the economic and reliability benefits of rooftop and carpark PV installations, it primarily evaluates feasibility at a macro scale. The analysis does not deeply integrate building-level load behavior, occupancy patterns, or operational energy management. Consequently, the linkage between PV generation, real demand profiles, and climate-responsive performance optimization remains underexplored [28]. A simple procedure determines the results of the proposed photovoltaic device based on solar radiation measurements at Shakra and the main campus of Shaqra University. A rooftop PV system was designed for a university building in Pakistan by the Homer Pro software. The program used the hourly load profile to model a steady-state system [29]. A complete picture of energy consumption was provided to assess the energy rating factors measured in kindergartens, schools and university buildings located in southern Finland [30]. In recent years, the energy efficiency

requirements in Finnish building codes have become significantly stricter. A rooftop photovoltaic (PV) power system is being implemented at the University of Surabaya, Indonesia, to generate electricity in addition to reducing greenhouse gas (GHG) emissions that can be generated by a solar rooftop photovoltaic system using the SolarGIS pvPlanner software [31]. A design methodology for the integration of photovoltaic cells (PVs) at an early stage of design (EDP) involving a demonstration of PV modules at the School of Design and the Environment (SDE) at the National University of Singapore (NUS) is presented in [32].

*Energy Audit in University Buildings and Campus*

Although energy audits are widely recognized as essential for improving efficiency in university buildings, many studies, including the work by Akbarova and Mammadov (2018) [10], focus primarily on assessment and thermal comfort estimation. These approaches provide valuable diagnostics but often stop at evaluation rather than proposing integrated operational or renewable energy solutions. As a result, the transition from audit findings to comprehensive, climate-responsive energy management strategies remains limited [10]. Fabrizio et al. estimated the energy consumption at the National Autonomous University of Mexico by comparing between results from energy audits and electricity bill for the whole campus. They applied retrofitting strategies for air conditioning, lighting, heating hybrid system and refrigeration [33,34]. Reductions in energy and $CO_2$ emissions were achieved with values of 7.5% and 11.3%, respectively. Similarly, Magrini et al. highlighted the value of campus-wide energy audits for strategic planning. Their findings also reveal limitations when applied to historically constrained buildings such as the University of Pavia. The study emphasizes planning considerations rather than practical implementation pathways for existing structures. Consequently, scalable and adaptable energy management solutions, suitable for diverse building typologies, remain insufficiently addressed [35]. Nevertheless, considerable energy savings can first be implemented at university campuses. A detailed study of Guangzhou University's (China) buildings energy audit was conducted by Lu et al. (2017) [35]. The study relied on collecting data about lighting, equipment, air conditioning, and other systems, which were then compared against energy efficiency benchmarks; based on these comparisons, effective measures were proposed to improve energy efficiency. Recent studies in hot arid countries indicate that energy audits in hot arid regions require integrated approaches combining long-term measured data, adaptive operational control, and renewable energy alignment. Therefore, a clear theoretical gap remains in linking audit findings with climate-specific performance optimization strategies for educational buildings in hot arid environments [36–38].

Based on the research problem, the research question addressed is as follows: How can existing university buildings in hot arid climates reduce energy demand through a realistic integration of on-site PV generation and low-cost operational control, without major architectural retrofit? Thus, this study aimed to optimize energy consumption in a higher education building (the Electrical Engineering Department, Assiut University, Egypt) by integrating photovoltaic panels and a smart control plan for regulating energy and improving indoor comfort without having to introduce significant changes in the building architecture. Here, the focus is on introducing an energy reduction plan for existing educational buildings in hot arid climates. In addition, the applied experience drawn from the study can be transferred for use in other educational buildings within Assiut University campus as well as other similar buildings in other higher education institutions located in hot arid climates, with the aim of creating smart campuses.

Although numerous studies have addressed energy auditing, photovoltaic (PV) integration, and building energy management in university facilities, these approaches are

often examined independently rather than within an operational framework in hot arid climates. Most previous research relies heavily on simulation-based analyses or Building Energy Management Systems (BEMSs), with limited focus on practical, low-cost strategies suitable for existing educational buildings operating under budget constraints. Furthermore, few studies combine long-term measured energy consumption data with a realistic PV system design that explicitly accounts for shading effects and actual occupancy schedules. This study addresses these gaps by proposing an integrated methodology that links multi-year energy audit data with optimized rooftop PV design and a schedule-based smart control strategy that does not depend on complex sensor systems. The novelty lies in demonstrating a climate-responsive, cost-effective, and scalable framework that aligns peak solar generation with cooling-dominated demand patterns, offering a practical pathway toward sustainable energy management in university buildings located in hot arid regions.

## 2. Methodology

High outdoor air temperature in a hot arid climate affects indoor air temperature and reduces indoor thermal comfort for all the users of the educational building. Consequently, this thermal discomfort leads to increased HVAC energy consumption and total annual energy consumption. To achieve improved energy efficiency in the educational building, this research focused on reducing total energy consumption by integrating PV systems and applying a smart control system. Accordingly, this study was structured according to two main phases, as shown in Figure 1.

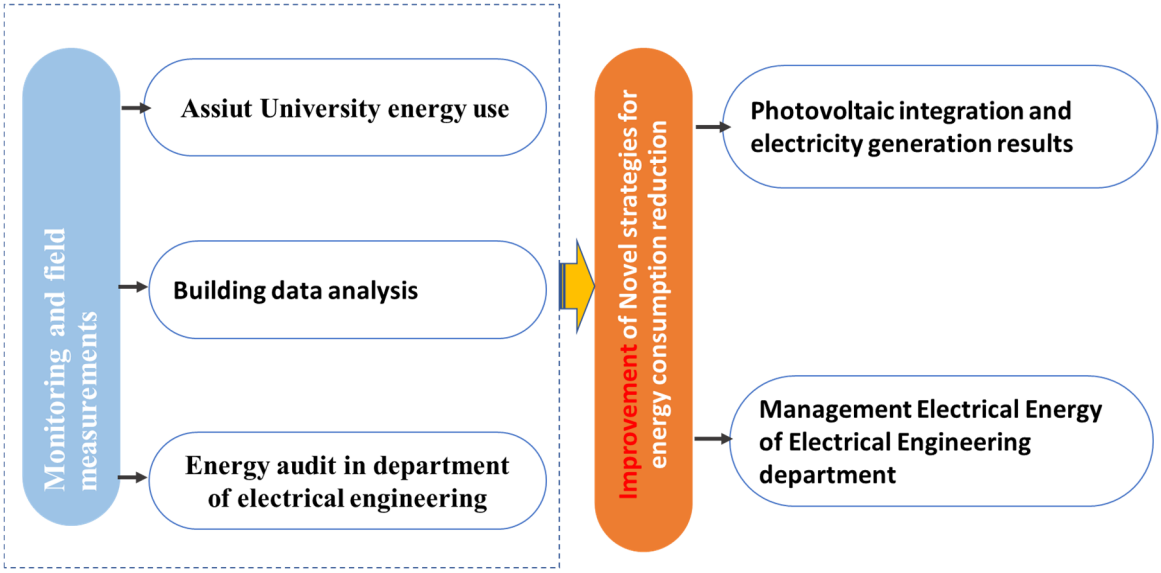



**Figure 1.** The proposed methodology.

Firstly, field measurements for energy consumption, over a five-year period from 2009 to 2014, were conducted to provide a clear understanding of long-term trends in Assiut University. Additionally, power consumption according to each building type in the academic year 2014/2015—in terms of total annual energy consumption for all buildings in the university campus—was calculated to demonstrate the energy consumption of educational buildings, which represents one-third of the total consumption based on the capacity of the transformer feeding these loads. Then, the building of the Electrical Engineering Department in the Faculty of Engineering complex at Assiut University, Egypt, was chosen as a case study. The electrical power load in the Electrical Engineering Department includes lighting, HVAC, fans, and other loads that were calculated and analyzed based on field surveys to identify the percentage of different loads of total energy consumption. The

building has different types of HVAC: Carrier, Sharp and Unionair. The HVAC capacity ranges from 11 units of 1.5 HP, 7 units of 2.25 HP, 11 units of 3 HP, 6 units of 4 HP, 27 units of 4.5 HP, 1 unit of 5 HP. After that, the total electrical energy consumption was calculated on working days from Saturday to Thursday for occupancy hours from 8 a.m. to 6 p.m. during the academic year of 2019 in the first semester. Most students' occupancy in classes ranges from 25 to 30 students. Furthermore, energy consumption was measured for one week on weekdays for 24 h using measurement devices (Fluke 434-II and 435-II Power Quality and Energy Analyzers produced by Fluke Corporation, which is headquartered in Everett, WA, USA and accuracy kWh (kVAh, kvarh) i430-Flex 10× depending on clamp scaling and V nominal ± 1% ± 10 counts). Secondly, PV panels were installed on the roof to generate electricity. The shading factor and tilt angle were calculated to ensure a realistic estimation of the energy yield. Additionally, improvements in the overall energy efficiency were calculated using the smart control flowchart that depends on schedules rather than complex sensors to facilitate implementation.

### *2.1. Renewable Energy Integrated for the Electrical Engineering Department*

Integrating photovoltaic systems into the building allows it to produce part of its own clean electricity, reducing reliance on the grid and lowering carbon emissions. Using the available roof areas for solar panels improves the overall energy efficiency and makes better use of existing building surfaces. In addition, the photovoltaic (PV) system supports sustainability goals and provides a real-world learning opportunity for students and researchers in the Electrical Engineering Department. The Electrical Engineering Department building consists of a first floor with an area of 911.25 $m^2$ and a second floor covering 2693.25 $m^2$. These available areas provide suitable space for installing a photovoltaic (PV) system to generate renewable electricity on site. Based on the local solar conditions, the annual incident solar energy on these surfaces is estimated at 903.9245 MWh, allowing for the installation of a 67 kW PV array, with the energy output calculated using a global model that accounts for temperature effects [39,40]:

$$E = A.G.r.P_R.\left(1 + \alpha_p.(T_a - T_{st})\right)$$

where $E$ = energy (kWh)

$A$ = total solar panel area ($m^2$)

$r$ = solar panel yield (%)

$G$ = annual average irradiation on tilted panels (shadings not included) *

$P_R$ = performance ratio, coefficient for losses (range between 0.9 and 0.5, default value = 0.75) reflects typical fixed rooftop PV systems in hot climates

$\alpha_p$ = the temperature coefficient of power (%/°C)

$T_a$ = ambient temperature in the current time step (°C)

$T_{st}$ = PV cell temperature under standard test conditions (25 °C)

### *2.2. Effect of Shading*

The shading factor f can be calculated from the tilt angle. Figure 2 shows the shading effect from tilt angle [30]. This factor is used to calculate the effective area of PV arrays that can contribute to generating energy without shading. Adopting a PV panel tilt angle equal to the site latitude is a commonly applied rule of thumb for fixed PV systems aimed at approximating optimal annual energy yield.

$$f = \frac{l}{d}$$

where $l$ is width of PV array facing sun, and $d$ is the full distance of projection of the PV array and its shading. The distance $d$ is considered the effective area, and it can be calculated as percentage of $l$, and the shading factor $f$ can be calculated using the following equation:

$$\alpha = \arctan\left(\frac{f.sin\ \beta}{1 - f.cos\ \beta}\right)$$

where $\alpha$ is the shading angle and $\beta$ is the tilt angle.

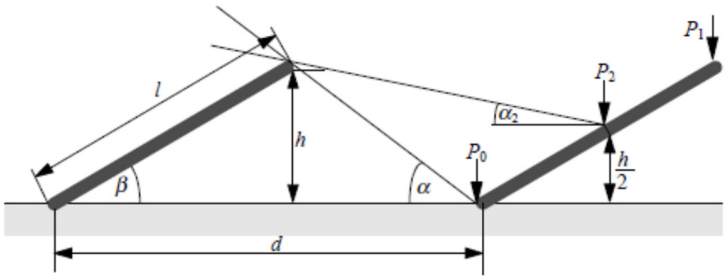
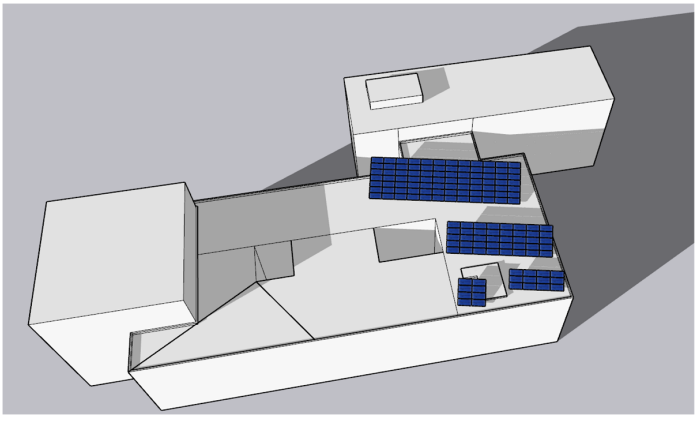



**Figure 2.** Shading effect from tilted angle.

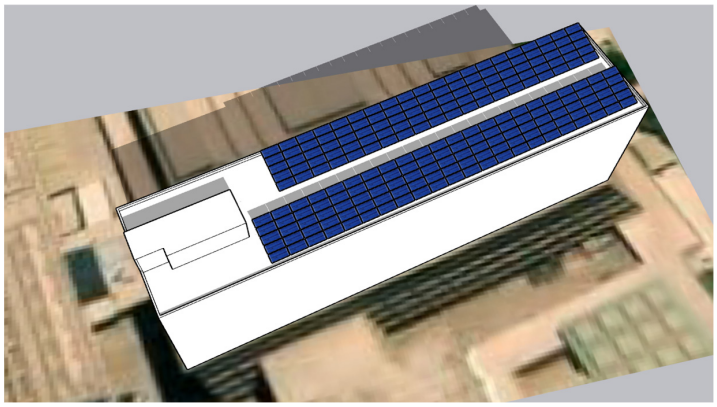
In this study, the shading angle $\alpha$ is equal to the tilt angle $\beta$. The tilt angle is equal to the latitude of site location. Assiut is located at 27.18° N latitude and 31.16° E longitude. The shading factor is 0.562 and $d = 1.78l$. The effective area is 0.562 from total area. This was introduced as a conservative geometric condition to prevent interrow self-shading at solar noon under the worst-case alignment. This simplification was selected for practical rooftop implementation and to avoid overestimation of effective areas. These clarifications strengthen the transparency and reproducibility of the PV modeling approach.

The annual average irradiation on tilted panels (G) of the Electrical Engineering Department according to the National Solar Radiation Database (NREL) at the site location (27.18° N latitude and 31.16° E longitude) was examined. Therefore, consideration of shading is essential to ensure stable and efficient electricity generation from the photovoltaic system, as even partial shading can significantly reduce the power output. Selecting a tilt angle equal to the site latitude helps maximize annual solar irradiation while maintaining a shading-free arrangement between PV rows. The calculated shading factor limits the installation to the effective roof area only, ensuring realistic estimation of PV capacity and preventing overestimation of energy yield. In addition, the use of reliable solar irradiation data from the National Solar Radiation Database (NREL) improves the accuracy of annual electricity generation predictions and supports sound PV system integration for the building. Figure 3 illustrates the distribution of solar modules across the building roofs.



(**a**) The Electrical Engineering Main Building

**Figure 3.** *Cont.*



(**b**) Electrical Engineering Laboratories Building

**Figure 3.** A 3D drawing.

### *2.3. Climate Data (Analysis)*

Assiut city is located in the southern part of Egypt and on the eastern side of the River Nile, with a latitude of 27.05° N and a longitude of 31.02° E. The climate of this region is hot and dry; Assiut has a maximum temperature that ranges from 38 °C to 43 °C and a minimum temperature ranging from 14 °C to 21 °C in the summer months (May–October). As for the winter months (November–April), it has a maximum temperature that ranges from 24 °C to 38 °C and a minimum temperature ranging from 3 °C to 9 °C. The difference between high and low temperatures is big enough to produce stress on air conditioning systems: ranging between 10 °C per day and 30 °C per month, as shown in Figure 4.

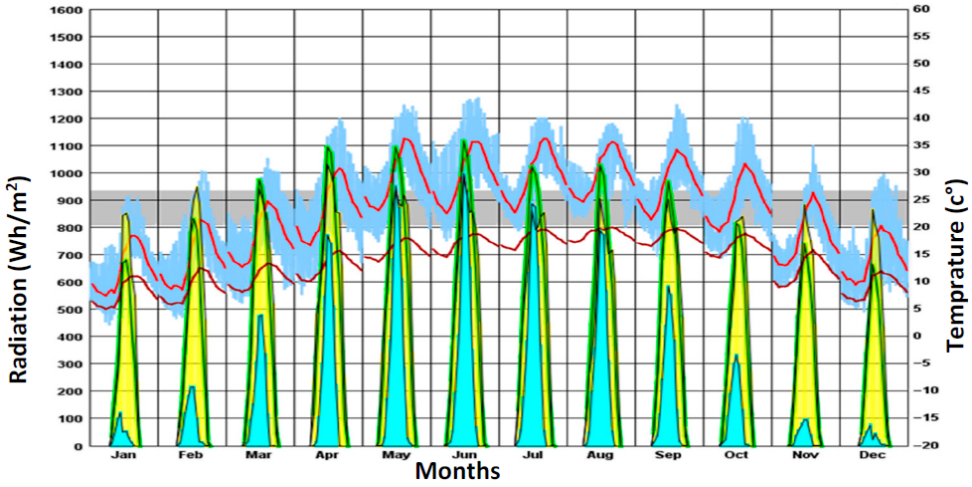



**Figure 4.** The monthly diurnal averages of Assiut city (Climate Consultant software 6).

### *2.4. Case Study Building Description*

The campus of Assiut University is located in the center of Assiut city in the south of Egypt, 375 km from Cairo. The main campus consists of 17 faculties, 3 institutes, 2 residential compounds, and a sports city occupying an estimated area of 232 hectares. The campus follows the orthogonal urban pattern forming an orthogonal street network. The street network axis is always oriented to the north–south axis and the east–west axis. Consequently, most of the university buildings are oriented in the same direction. The buildings forming the site are made of the same material and share the same architectural features, including their façades. However, the shapes of educational buildings are divided into two main shapes: linear buildings and central buildings.

The case study is the Electrical Engineering Department in the Faculty of Engineering at Assiut University, Egypt, as shown in Figure 5. This building was selected because it

is an educational building that represents the two main shapes of the buildings on the campus of Assiut University. Moreover, this building was subject to high annual total energy consumption.

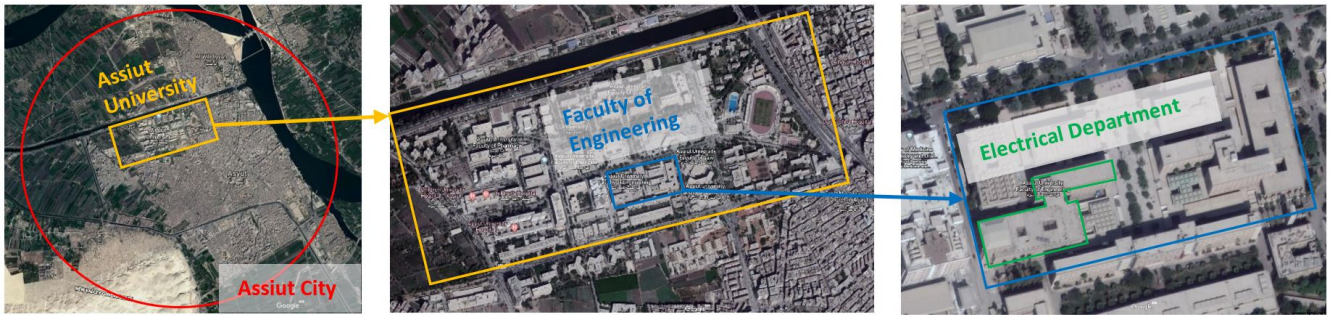



**Figure 5.** The location of the Electrical Department at Assiut University (satellite images).

The Electrical Engineering Department is located in the faculty of Engineering, Assiut University. It is mainly used for teaching and scientific research. It consists of two buildings linked by a pathway: the first is a five-floor building and the second is a three-floor building, as shown in Figure 6. The first building floor area is 911.25 $m^2$ and the second building is 2693.25 $m^2$. The two buildings include about 13 classrooms, 29 labs, 31 faculty offices, as well as service rooms and areas. As an exception, the second building has four administrative offices and two courtyards. The detailed floor plans are shown in Figure 6.

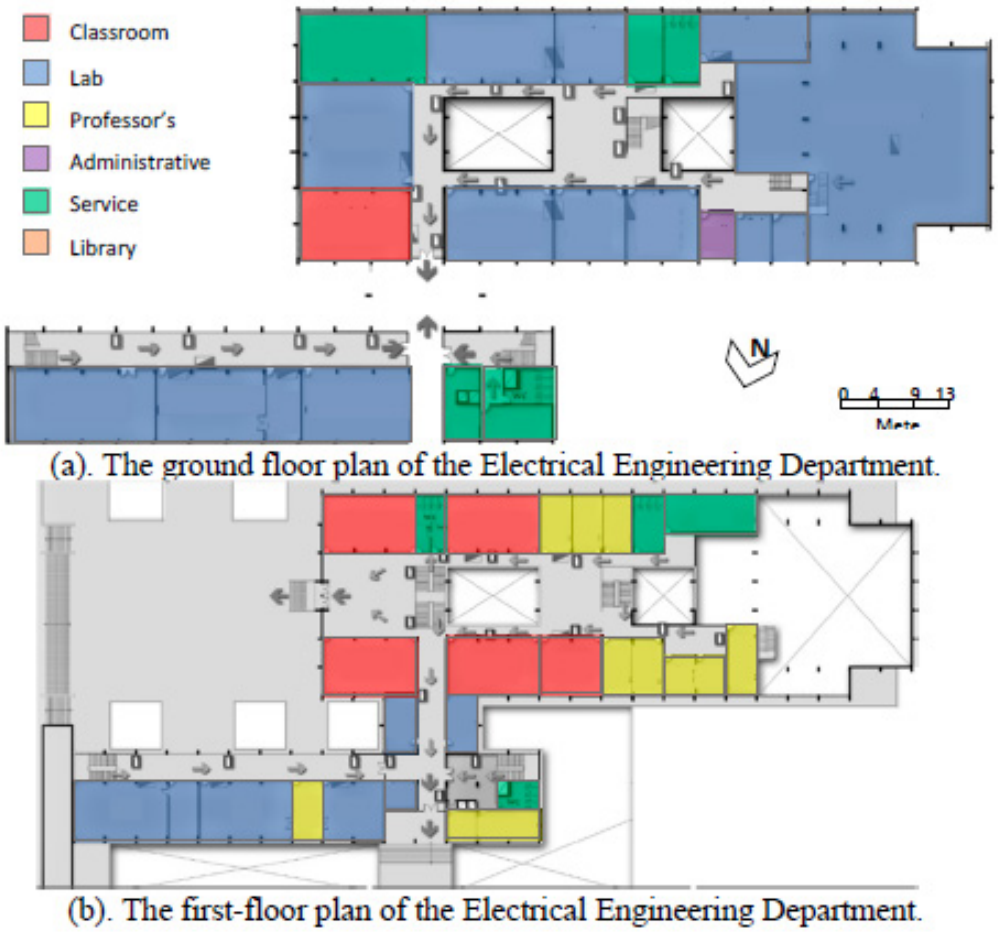
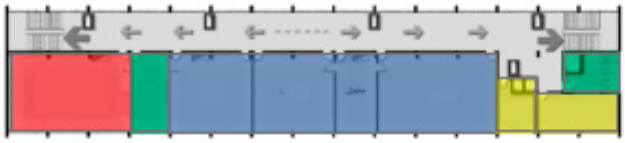



**Figure 6.** *Cont.*



(c). The second-floor plan of the Electrical Engineering Department.



(d). The third and Forth floor plan of the Electrical Engineering Department.

**Figure 6.** Different floor plans of the Electrical Engineering Department.

## 3. Results and Discussion

### *3.1. Energy Consumption Audit and Analysis for Assiut University and Electrical Engineering Department*

(a) **Assiut University energy use**

Assiut University main campus is fed through the main switch panel. There are two main buses that feed nine sub-feeders on each bus. Each sub-feeder has an energy meter. The energy is usually recorded from energy bill computation. The five-year duration, over which the energy consumption analysis was conducted, gives a grasp of the trends and seasonal patterns of energy consumption in buildings. The following parameters can be studied accurately for long-term patterns, not just short-term fluctuations: climate conditions, occupancy, and the operational behavior. Such long-term analysis enhances the credibility of energy efficiency measures, as well as peak demand patterns. In general, officials can make informed decisions concerning energy management and the sustainability of planning in educational buildings.

To structure any missing part and clarify the points that need to be covered to ensure data accuracy, the data source was precisely identified to ensure verifiability: time intervals and the total collection period were specified. It was confirmed that all data follow the same timeframe. Maintenance periods or forced system shutdowns, that do not reflect actual consumption, were also excluded. When illogical spikes in consumption occur due to metering errors or an exceptional event, any value exceeding three standard deviations from the average is considered an anomaly. A distinction is also made between "technical anomalies" (meter malfunction) and "operational anomalies" (e.g., unexpectedly running air conditioners on an exceptionally hot day). Sometimes, campus data are incomplete due to sensor or network outages. Therefore, linear interpolation is used for very short gaps.

Figure 7a shows variations in the yearly average temperature for the academic years from 2009/2010 to 2014/2015. It shows that the annual energy consumption increases as the yearly average temperature increases and vice versa. This can be explained by the effect of temperature on the energy consumption in building air conditioners. Figure 7b shows the variation in the monthly average temperature and the monthly energy consumption for the academic years from 2009/2010 to 2014/2015. It shows that the annual energy consumption increases as the yearly average temperature increases. This can be explained by the effect of temperature on energy consumption in building air conditioners. The lack

of smooth variation in energy consumption relative to the average maximum temperature is attributable to human activity patterns and the university's operational characteristics. Figure 8a shows the effect of the average max temperature on energy consumption. The average maximum temperatures vary between around 15° and 40°, where energy consumption varies from 2 GWh to 5 GWh. The linear relation between energy and daylight hours is as follows: E = 0.0818T + 1.1987. This relationship shows that the coefficient of determination ($R^2$) = 0.4772. The energy consumption remains relatively stable when the average maximum temperature is below 25° and tends to increase as temperature rises above this threshold. The figure shows that there are 19 groups of daily hours as the variation in daily hours for different years seems to be constant. However, the variations in energy consumption for the same daily hours depend on temperature at the relevant time and shift between summer and winter conditions in response to occupants' thermal comfort requirements. Figure 8b shows the effect of daylight on energy consumption. The daylight hours vary between around 10 h and 14 h, where energy consumption varies from 2 GWh to 5 GWh. The linear relation between energy and daylight hours is as follows: E = 0.3777h − 1.0199. The figure shows that there are 12 groups of daily hours as the variation in daily hours for different years seems to be constant. However, the variations in energy consumption for the same daily hours follow the same seasonal temperature pattern, shifting between summer and winter conditions in response to occupants' thermal comfort requirements.

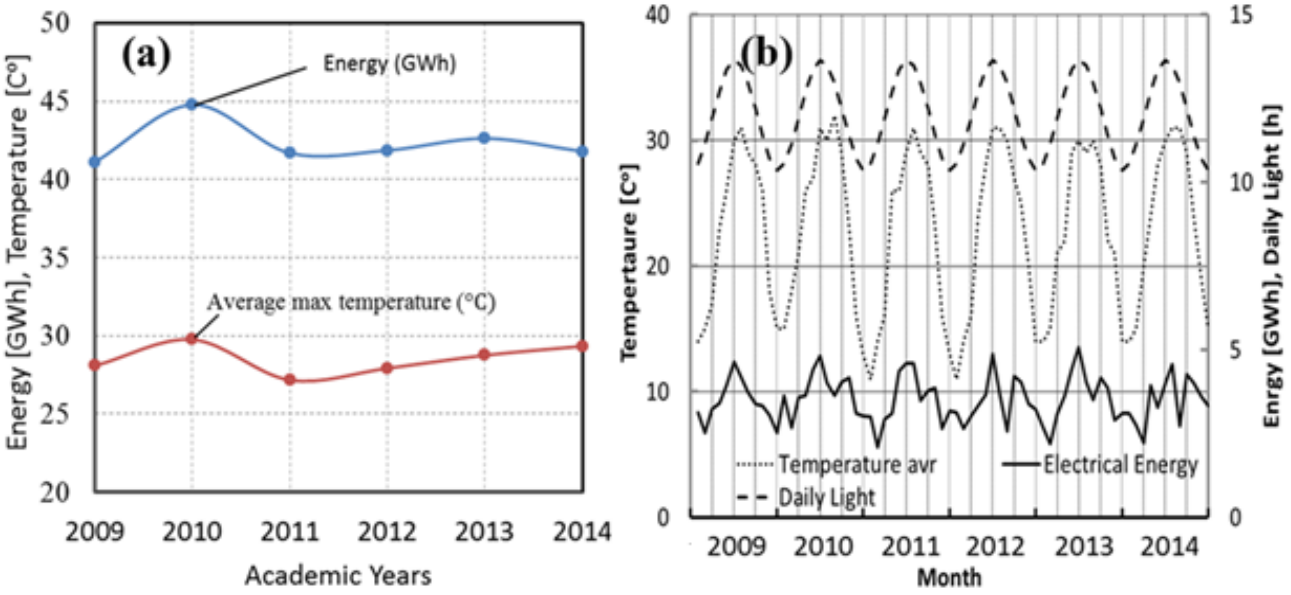



**Figure 7.** (**a**) Energy consumption against average temperatures of the year, (**b**) monthly power consumption and temperature from 2009 to 2014.

Figure 9 shows the radar presentation of energy consumption in Assiut University from 2009 to 2014. It shows that energy consumption increases in summer as the temperature increases and decreases in winter as the temperature decreases. However, it is notable that when the weather changed from cold to hot, energy consumption increased slowly compared to the decrease in energy consumption for the change in the weather from hot to cold. This can be explained by the effect of human thermal comfort in changing seasons. Additional contributing factors include the thermal storage in building materials and the characteristics of Assiut's climate, given the significant diurnal temperature range.

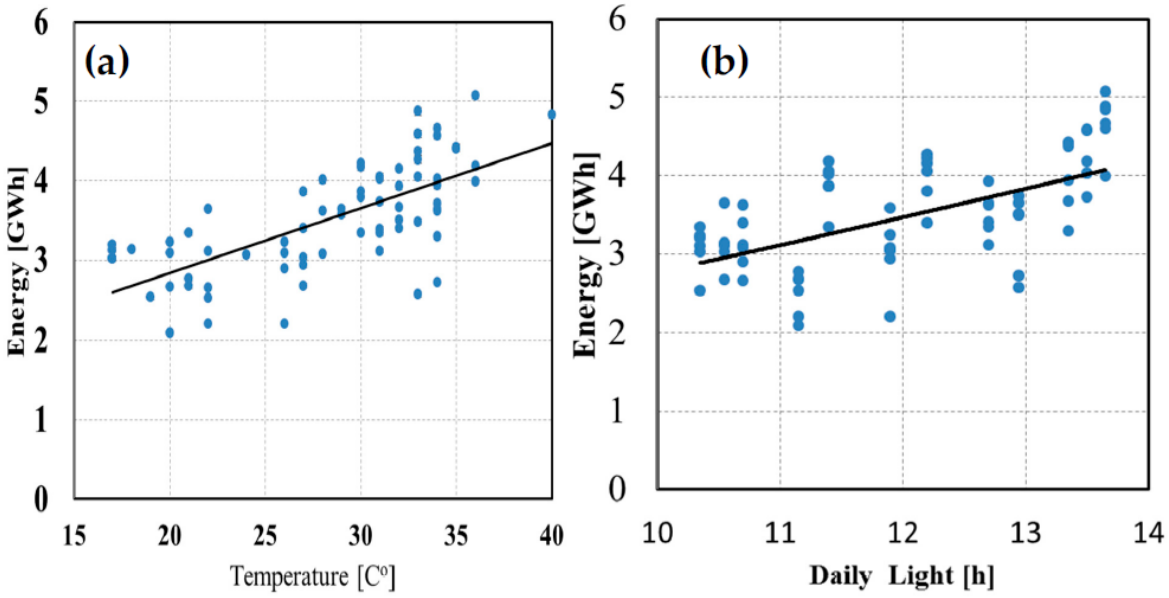



**Figure 8.** (**a**) Average max temperature vs. energy consumption, (**b**) daily light vs. energy consumption.

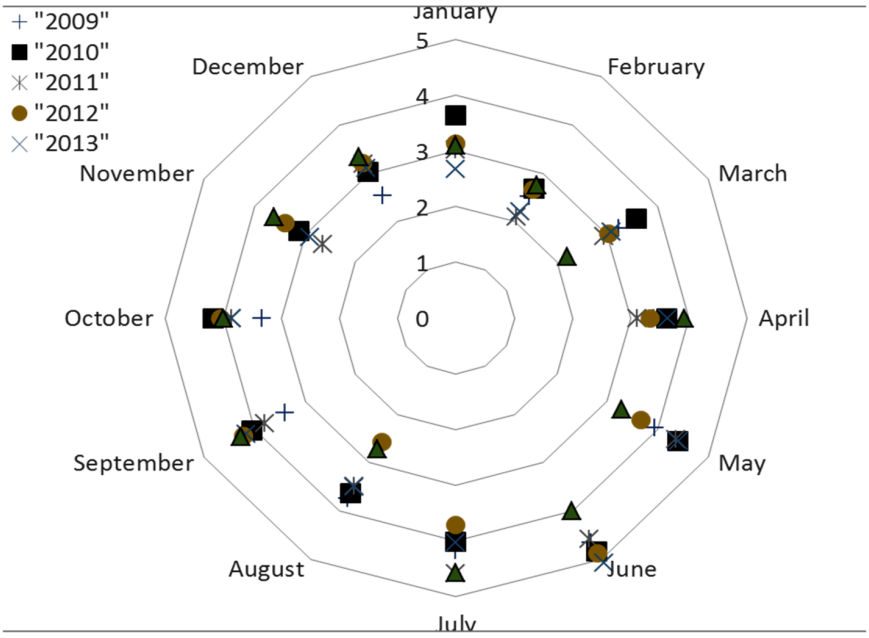



**Figure 9.** Radar presentation of energy consumption vs. months (2009 to 2014).

Figure 10 shows the power consumption of different buildings in Assiut University. It is clear that the energy consumption of the educational buildings sector in Assiut University comprises 34% of the total energy consumption. In Egypt, the academic year extends from the middle of September to the middle of January for the first semester and from the middle of February to the beginning of June for the second semester, a total of 8 months. Figure 11 shows the relation between the monthly energy consumption and outdoor temperature in Assiut University. The energy consumption of Assiut University usually increases in May and June as the temperature increases due to using air conditioners and mechanical fans, consistent with the findings of Agdas et al. (2015) and Chung and Rhee (2014) [2,3]. As the temperature starts to decrease in November, energy consumption decreases despite the fact that teaching continues till the end of January. This is because the energy consumed goes only for lighting, computers, and laboratory devices, while all the air conditioners and fans are turned off.

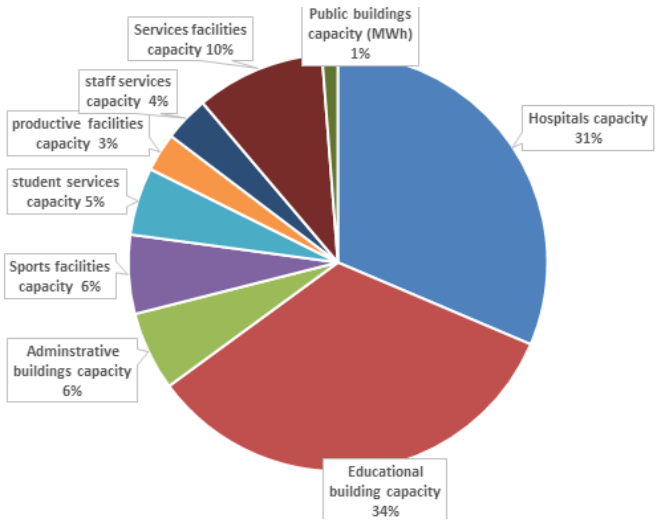



**Figure 10.** Assiut University power consumption according to each building type in the academic year 2014/2015.

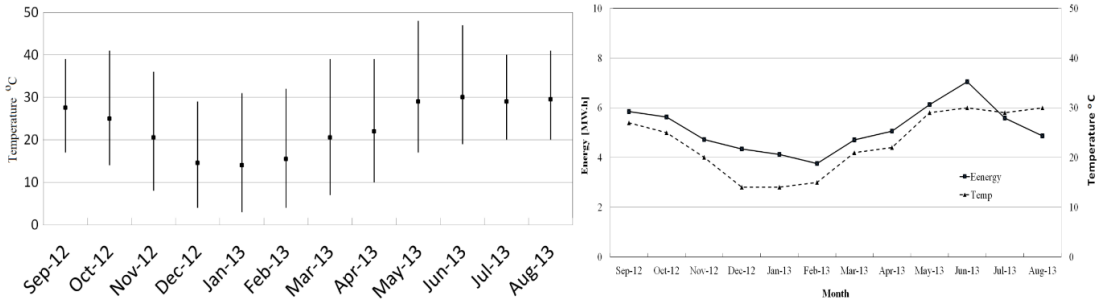



**Figure 11.** Assiut University temperature and monthly energy consumption for the academic year 2012/2013.

(b) **Building data analysis**

Table 1 shows the calculated loads in the Electrical Engineering Department based on the field survey. The electrical power loads in the electrical engineering department include lighting, HVAC, fans, and other loads. The number of each system was collected in addition to the electrical power needed for them, as shown in Table 1. The lighting system consists of 40-, 20-, and 250-watt lamps that take about 81,760 watts for the total building. Meanwhile, the HVAC system consists of 112 air conditioners in the whole building that take about 250,656 watts. As for the fans, there are 166 fans, which take about 14,110 watts. The total electrical power for the electrical engineering department is 351,526 watts, where the lighting, HVAC, and fans represent 23.3%, 71.3%, and 4%, respectively, of the total electrical power, as shown in Figure 12. This agrees with previous research about energy consumption for lighting, HVAC and fans depending on building type and operational schedules with a maximum load for air conditioning [3,4].

**Table 1.** The total calculated loads in the Electrical Engineering Department.

| Floor | Lighting | Fans | HVAC | Other Loads | Total |
|---|---|---|---|---|---|
| Ground | 437 (40 w)<br>40 (250 w) | 36 | 9 | | |
| First | 442 (40 w)<br>84 (20 w) | 48 | 34 | | |
| Second | 565 (40 w) | 59 | 46 | | |

**Table 1.** *Cont.*

| Floor | Lighting | Fans | HVAC | Other Loads | Total |
|---|---|---|---|---|---|
| Third and Fourth | 308 (40 w) | 23 | 23 | | |
| Sum | 1876 | 166 | 112 | | |
| Total Electrical Power | 81,760 W | 14,110 W | 250,656 W | 5000 W | 351,526 W |

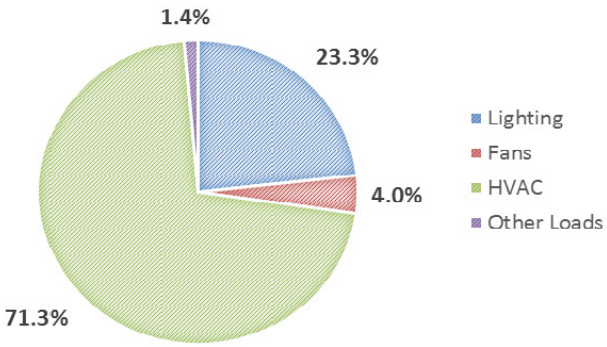



**Figure 12.** The percentages of the electrical power loads in the Electrical Engineering Department.

(c) **Energy audit in the Department of Electrical Engineering**

Figure 13 shows the total electrical energy consumption calculated on weekdays (Saturday–Thursday) for one week, and the electrical energy consumption was calculated for the occupied hours (8 a.m.–6 p.m.). It is clear that Saturday and Thursday are the lowest days for electrical energy consumption due to the beginning and the end of the week, especially Thursday because the students finish early and the professors have fewer working hours. The highest electrical energy consumption occurred on Monday with a value of 45 kWh due to the existence of all the staff in the building between 9 a.m. and 1 p.m. The energy audit monitoring for one of the typical weekdays is shown in Figure 14. Electrical energy consumption for the occupied hours ranges between 53 and 74 kWh. The week presentation of measured and calculated values illustrates the comparison between measured and calculated data over one week. This comparison demonstrates the dependence of energy consumption on the work schedule; furthermore, the discrepancy between measured and calculated values indicates the extent of arbitrary energy consumption that could be avoided.

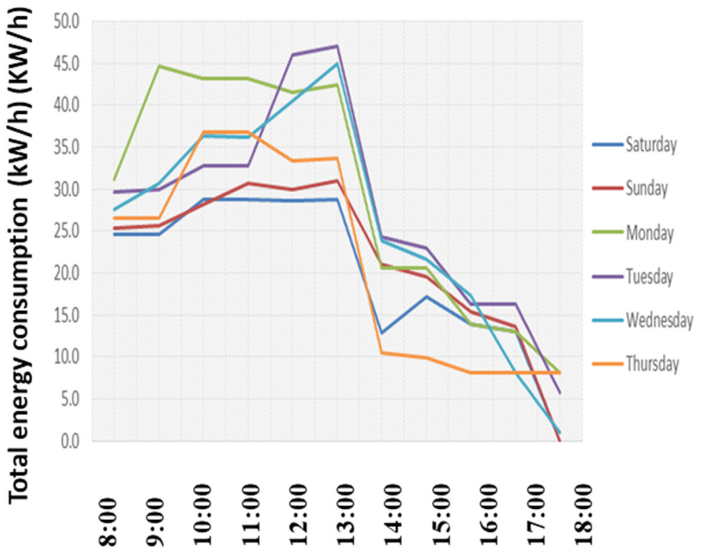



**Figure 13.** The weekly calculated electrical energy consumption of the occupied hours of the weekdays based on the work schedule.

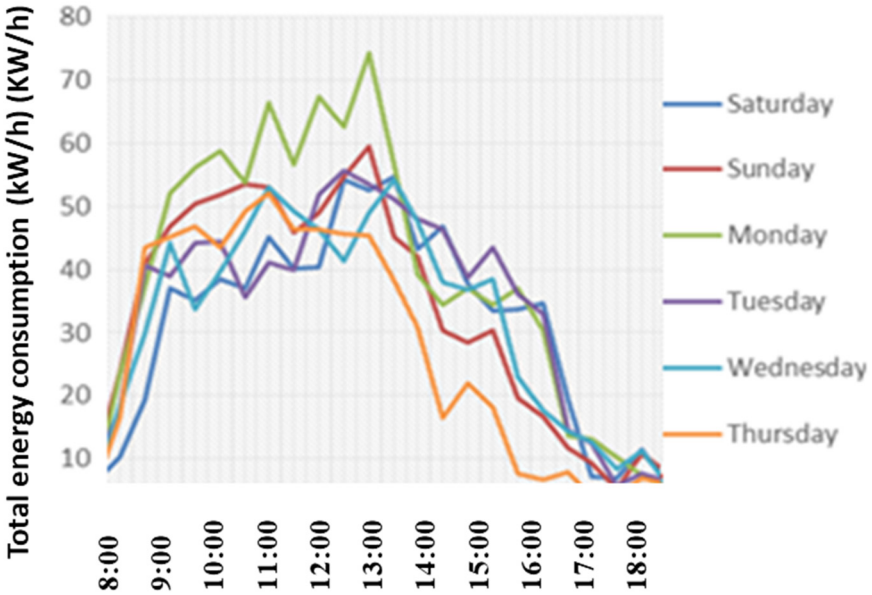



**Figure 14.** The weekly measured electrical energy consumption of the occupied hours of the weekdays.

### *3.2. Improvement in Novel Strategies for Energy Consumption Reduction*

The need for improving operational efficiency, energy costs, and mitigating environmental impacts in higher education buildings is undeniable. The Electrical Engineering Department experiment combines renewable energy generation with simple, practical demand management strategies. The PV analysis shows significant generation during months of high solar irradiance; accordingly, two strategies are introduced here to enhance overall energy performance. The first strategy focuses on maximizing the use of existing PV systems for more effective management of electrical loads. The second one is concerned with eliminating unnecessary electricity consumption through a smart control system according to realistic occupancy patterns, work hours, and space usage. It is crucial to develop, integrate, and maintain such strategies. The ultimate goal is to minimize energy waste, enhance reliability, and contribute to more sustainability and intelligence of higher education buildings.

(a) **Photovoltaic integration and electricity generation results**

Figure 15 shows a comparison between the electricity generation from PV systems integrated on the building roof and the monthly electricity consumption of the Electrical Engineering Department. It is clear that the electricity generated by the PV system installed on building 2 is larger than that of building 1, indicating larger installed capacity, better orientation, and higher system capacity. The total monthly PV outputs range between 33 and 35 MWh during summer months due to higher solar irradiance and longer daytime hours, which agrees with previous research [40]. Furthermore, the total PV output exceeds the electricity consumption during the summer season. In general, the results demonstrate that the PV systems significantly contribute to meeting electrical demands with high effectiveness during high-solar-availability months.

Figure 16 shows the weekly output energy of PV for the occupied hours of the weekdays. It is clear that the photovoltaic (PV) system deployed at the Electrical Engineering Department exhibits a generation profile that is well aligned with the building electricity demand during the occupied hours, not the university-wide demand. PV output increases steadily in the morning, reaches its maximum around solar noon, and declines toward the late afternoon, consistent with the diurnal pattern of solar irradiance.

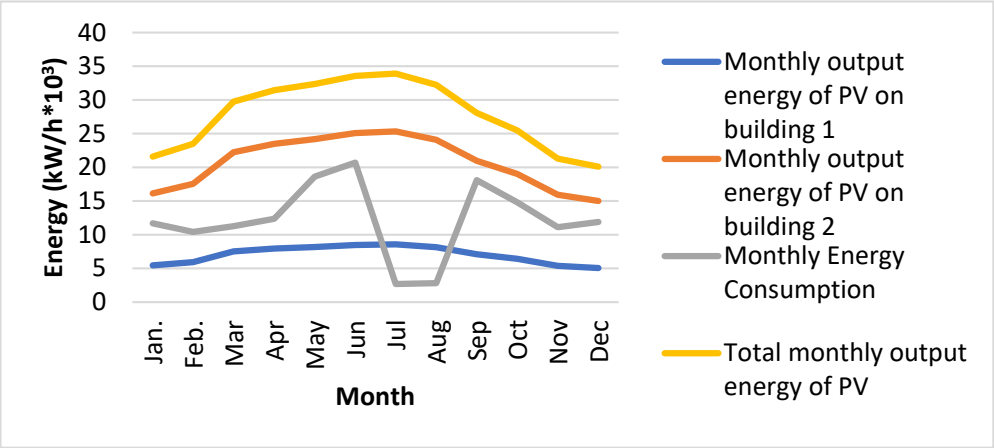



**Figure 15.** The comparison between the monthly output energies of PV and the energy consumption of electricity at the Electrical Engineering Dept.

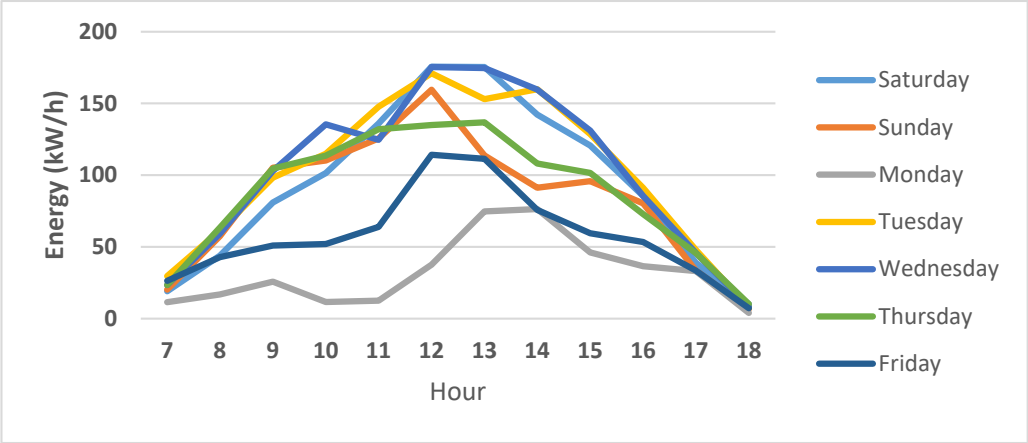



**Figure 16.** The weekly output energy of PV for the occupied hours of the weekdays.

Based on the high solar availability in Assiut city, PV generation exceeds the building electrical demand, resulting in surplus energy that can be exported to the Egyptian national grid. This surplus highlights the potential of building-integrated PV systems to enhance urban energy self-sufficiency and contribute to grid support within dense campus environments. The PV production is sufficient to offset the measured annual consumption of the building, not the university-wide demand. This reinforces the suitability of solar energy as a key component of sustainable urban energy systems.

(b) **Electrical Energy Management of the Electrical Engineering Department**

According to the smart control sketch (Figure 17) and the proposed flowchart (Figure 18), a practical approach is proposed for reducing energy consumption in the Electrical Engineering Department, grounded in real-world daily activities. The core principle of the smart system is to supply power only when spaces are occupied, linking electricity activation directly to staff and student schedules.

According to the flowchart, operation starts at 8:00 a.m. on working days, with room usage updated on an hourly basis. Such updates are crucial as occupancy levels change many times during the day. According to the smart control diagram, rooms and corridors are divided into smaller zones. Thus, control is easier, ensuring the elimination of unnecessary energy consumption. This enhances energy reduction in unused spaces. A scheduled complete shutdown during weekends eliminates potential standby and phantom loads, and a comparison was incorporated using measured versus calculated load profiles,

demonstrating that up to approximately 40% of non-essential consumption (mainly HVAC and lighting during unoccupied periods) can be avoided.

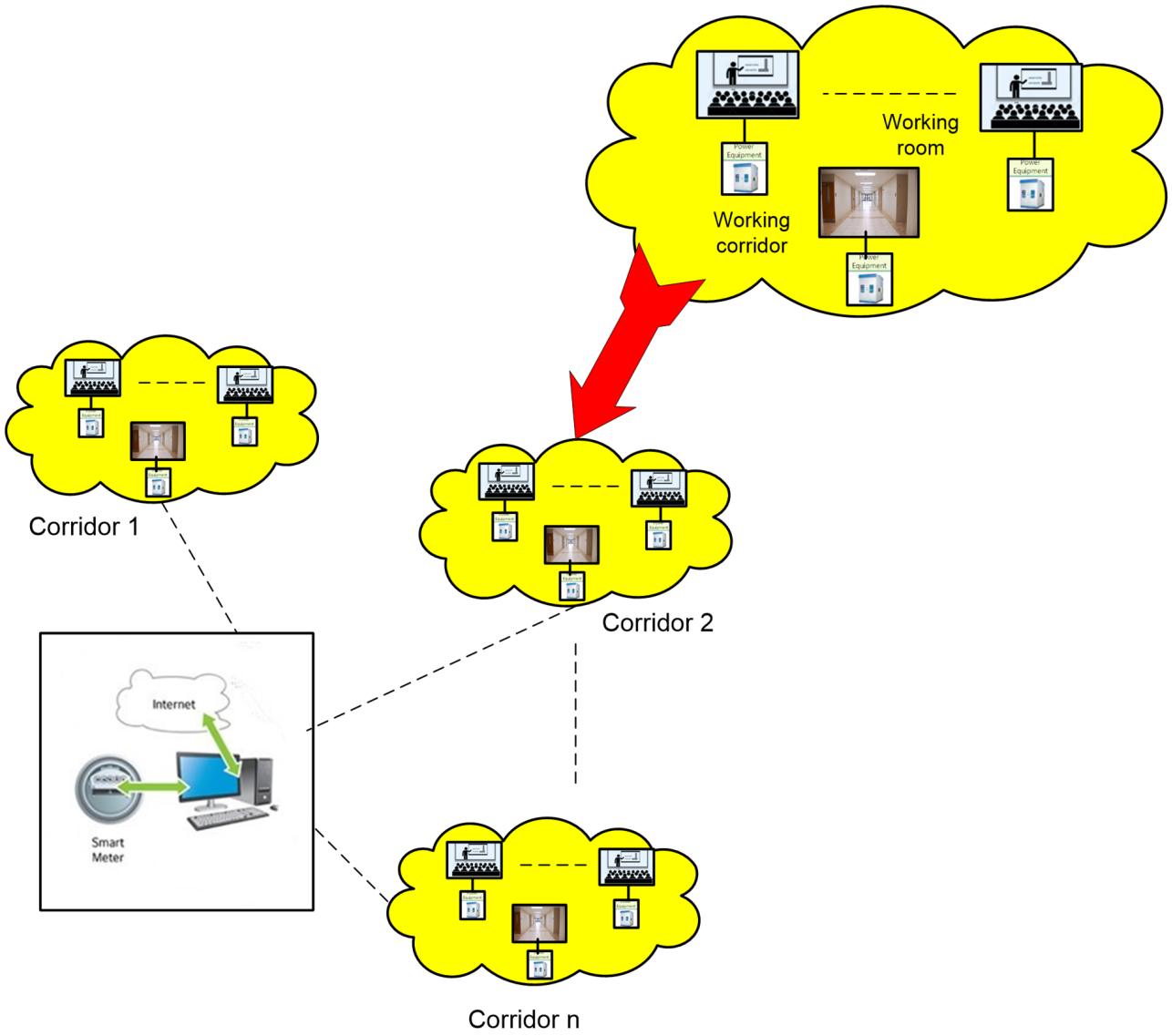



**Figure 17.** The smart control of Electrical Engineering Department.

The proposed strategy enhances energy efficiency and reduces costs of operation, without compromising comfort or daily activities. Adopting schedule-based control is more practical than relying on complex sensor networks, resulting in a cost-effective and straightforward system. Thus, the system is applicable to nearly all types of educational buildings, labs, libraries, lecture halls, and even administrative facilities, with an ultimate goal of sustainable campus management.

Therefore, the proposed strategy is most effective for cooling-dominated educational buildings with structured schedules (e.g., lecture halls and laboratories). In contrast, mixed-use or 24 h facilities (e.g., hospitals or research centers) would require adaptive or sensor-based control strategies rather than fixed schedule zoning.

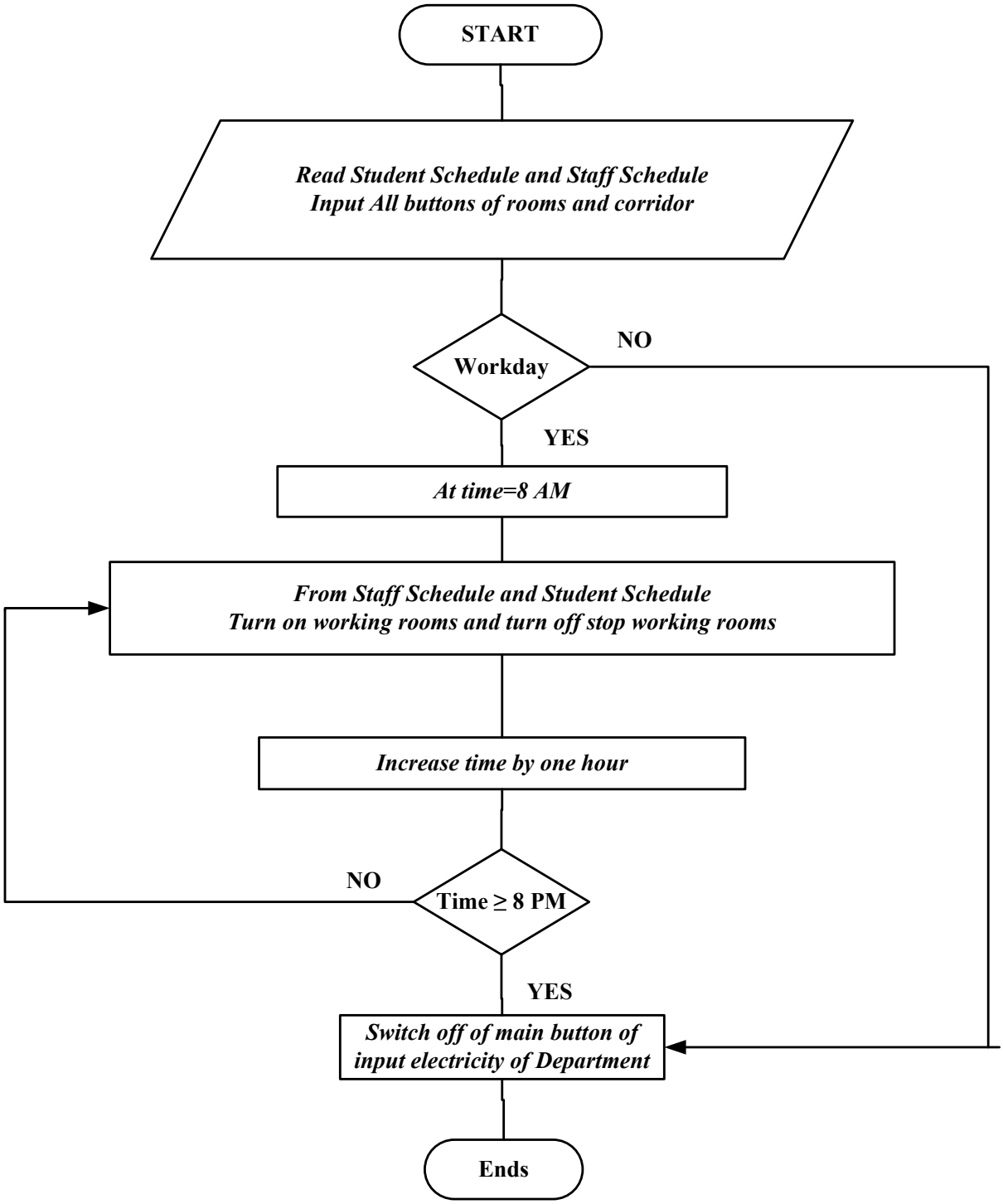



**Figure 18.** The flowchart of management electrical energy of Electrical Engineering Department.

## 4. Conclusions

This research develops a practical energy-saving strategy for the existing Electrical Engineering Department buildings at Assiut University, located in a hot arid climate, without relying on major architectural alterations. The strategy combines rooftop photovoltaic (PV) systems with a simple, yet effective, smart control approach tailored to building operation.

- Analysis of long-term electricity consumption data from 2009 to 2014 show a clear link between energy use and rising temperatures, largely influenced by occupancy behavior

and academic schedules, with the average annual peak consumption reaching about 30 GWh.

- During summer months, energy demand increases progressively with temperature and daylight duration, following linear relationships (E = 0.0818T + 1.1987 and E = 0.3777h − 1.0199), while remaining relatively stable when average maximum temperatures are below 25 °C. These correlations apply primarily to buildings where cooling loads represent the dominant share of total electricity consumption.
- For a typical occupied day, hourly electricity consumption ranges between 25 and 47 kWh, reflecting schedule-driven operational patterns within teaching-oriented facilities.
- Installing PV panels over an effective roof area equal to 56.2% of the total 3604.5 $m^2$ generates approximately 33–35 MWh annually under Assiut's solar conditions. This production is sufficient to offset the measured annual electricity demand of the case-study building, assuming similar load composition and unobstructed rooftop conditions.
- Moreover, applying a smart control plan based on users' schedules significantly improves energy efficiency without the need for expensive sensor-based systems.
- The proposed PV–smart control framework is, therefore, applicable primarily to similar university building typologies and climatic contexts, rather than universally transferable to all building types.

Overall, the proposed PV–smart control combination offers a realistic and scalable solution for reducing energy consumption in university buildings and can be easily extended to lecture halls, laboratories, libraries, and administrative facilities to cover the measured annual consumption of each building, not the university-wide demand.

Future research is recommended to include the following: (i) testing the framework in multiple buildings to validate cross-building reproducibility and (ii) evaluating economic feasibility under different grid export policies.

**Author Contributions:** Conceptualization, M.N., A.S.H.A., M.A. and M.B.B.H.; methodology, M.N., A.S.H.A., M.A. and M.B.B.H.; software, M.A.; validation, M.N., A.S.H.A. M.A. and M.B.B.H. formal analysis, M.N., A.S.H.A., M.A. and M.B.B.H., R.M.A.M.; investigation, M.N., A.S.H.A., M.A. and M.B.B.H.; resources, M.N., A.S.H.A., M.A. and M.B.B.H.; writing—original draft preparation, M.N., A.S.H.A., M.A. and M.B.B.H. R.M.A.M.; writing—review and editing, M.N., A.S.H.A., M.A. and M.B.B.H. R.M.A.M.; visualization, M.N., A.S.H.A., M.A. and M.B.B.H.; supervision, M.N., A.S.H.A., M.A. and M.B.B.H.; project administration, A.S.H.A.; funding acquisition, A.S.H.A. All authors have read and agreed to the published version of the manuscript.

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