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Enhancing the Energy Efficiency of Buildings by Shading with PV Panels in Semi-Arid Climate Zone

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Abstract: Solar energy is one of the most abundant and available forms of renewable energy. Reliance on the electricity network can be decreased and net-zero energy achieved by mounting photovoltaic power on the tops of houses. Photovoltaic arrays can also change how the roof's surface reacts to its environment. The influence of the structural system of a roof and weather on the energy consumption of a building is important. This research is concerned with focusing on the indirect effect of solar photovoltaic rooftop panels (shading effect) on the roof surface to see whether this effect is worth studying and calculating the total electrical load in the residential sector. Photovoltaic panels were modeled as a shading device, and the Integrated Environmental Solution-Virtual Environment Software was used to anticipate the monthly decline and growth in heating and cooling loads associated with the roof level. The influence of a photovoltaic system on a building's roof-related energy load was measured concerning low-rise residential buildings in Mafraq city, which belongs to a mild dry-warm temperature zone. The findings indicated that a solar roof structure decreased heat loss by 4.85% in the summer and boosted heat transfer by 5.54% in the winter. The results highlight that renewable energy is very important in our times due to climate change and the increased demand for electricity by the residential sector, which is stimulated to find multiple ways to decrease and adapt to this change, and the aim of this paper helps to encourage to use solar energy by identifying the indirect effect of solar panels on building's rooftops. This investigation also focuses on the value of offering essential instructions to who is concerned to the utilization of alternative energy to heat and cool structures, also will educate the public on a building's total energy requirements, which is critical for future green structure design.

Keywords: solar energy; rooftop; photovoltaic; shading; semi-arid desert region; Jordan

Citation: Albatayneh, A.; Albadaineh, R.; Juaidi, A.; Abdallah, R.; Zabalo, A.; Manzano-Agugliaro, F. Enhancing the Energy Efficiency of Buildings by Shading with PV Panels in Semi-Arid Climate Zone. *Sustainability* **2022**, *14*, 17040. https://doi.org/10.3390/su142417040

Academic Editors: Ali Bahadori-Jahromi and Elena Lucchi

Received: 24 October 2022
Accepted: 15 December 2022
Published: 19 December 2022

1. Introduction

Building energy usage contributes to 43% of overall global energy consumption. Furthermore, the usage of fossil fuels in residential properties accounts for approximately 33% of global greenhouse gas emissions. A large amount of energy usage is mainly related to energy loss and gains through the building's structure. In Jordan, the construction sector accounts for at least 43% of total electricity usage. Thus, every design modification that improves the energy efficiency of a building will generate considerable economic, social, and environmental advantages, in addition to a reduction in energy use. Researchers have considered ways to improve the energy performance of buildings in various climatic zones to achieve thermal comfort [1]. In the twenty-first century, regulators and others are aware that retrofitting existing structures will offer sustainability for urban development. This precisely captures the existing sustainability challenge: a significant amount of research emphasizes the energy-saving possibility of future construction projects, whereas existing buildings account for most global energy end-use and are responsible for 40% of global energy demand. Existing structures are enduring assets that have a major effect on their external environment during their existence; hence, there is a pressing need to adapt them in Jordan [2].

Heating, ventilation, and air-conditioning (HVAC) equipment account for more than half of all global annual energy consumption [3,4]. In 2019, space cooling accounted for 20% of all electricity used in buildings worldwide. Energy use for cooling systems is expected to increase from 32% of total building energy consumption in low-latitude countries (e.g., Africa, the Middle East, etc.) to 72% by 2100, driven largely by relatively warm outdoor temperatures that are a product of climate change. Because of its warm, dry, and semi-arid weather and harsh weather patterns, the Middle East is highly susceptible to the projected effects of climate change [5].

The increasing desire for enhanced thermal comfort in the building envelope is driving the demand for space cooling. The prevalence of cooling systems in the Middle East is over 65%. Reference [5] indicated in their literature review that, at our present times, there are 1.1 billion air-conditioning units (three units per capita) in the region, with that number expected to rise to 3.1 billion units (five units per capita) by 2050. The necessity for promoting this development in an efficient world has led to the establishment of multiple cooperative Green Building Codes on both a national and regional level (GBCs).

Jordan is a developing country spanning an area of 89,342 km^2. The kingdom is organized into 12 states, with Amman serving as the capital. Amman is also the most populous state, and is home to 42% of the country's population [2]. However, nations are shifting to a more substantial source of energy due to the precarious distribution chain for these resources during times of conflict and epidemics, and the finite nature of non-renewable resources. Jordan is one of the emerging regions that suffer from power generation and distribution, as it receives more than 94% of its energy. Jordan has also experienced two major power outages over the last two decades: in 2003, when Iraqi oil exports were affected due to war, and in 2011, when Egyptian natural gas reserves were suspended because of the Arab Spring. Ultimately Jordan was forced to look for more friendly, greener, available, and self-reliant assets, such as renewable power, at affordable costs due to the volatility of oil prices. Consequently, by 2020, Jordan's authorities aimed to fulfill 10% of their needs using renewable energy, such as wind, solar, and biomass resources, while reducing air greenhouse emissions and promoting economic development [6].

Jordan's fossil-based energy options are limited. In comparison to South and East European nations, the country is viewed as a rising energy consumer. However, its use of fossil fuels is entirely reliant on imported gas and oil from neighboring states. The sudden increase in the population and urbanization is driving up energy demand. Since 1980, the density of energy requirements has been continuously decreasing in most parts of the world, whereas the inverse correlation is evident in Jordan, with energy intensity climbing faster than GDP. The country's financial performance will be affected by such high energy density development, which will require more than 3% of GDP for fundamental energy investment by 2030, compared to 1% for the rest of the globe. Residential properties, for instance, are large energy users, with energy consumption practices varying widely from those in many Western nations. In Jordan, the residential sector accounts for up to 21% of total energy consumption and 42% of energy requirements. Solar radiation, on the other hand, is one of Jordan's most viable renewable energy sources. Average daily solar radiation ranges between 4 and 7 kWh/m^2, with about 300 sunny days per year, which corresponds to an annual average solar radiation of 1400–2300 kWh/m^2 [7]. Jordan has entered a new phase in alternative energy since enacting Law No. 13 of 2012. One of the most significant changes initiated by this law is the potential for exporting electricity production to electric utilities, with applicable prices being determined. Jordan accomplished 10% sustainable energy entry into the energy mix, including 1000 MW of wind and 600 MW of solar energy. Currently, renewable energy projects in Jordan supply the national power grid with 3–4%.

Jordanian residential energy usage is influenced by Jordan's climate and the nature of the terrain, as well as construction methods, structure attributes, and occupant attitudes. Several studies have calculated that HVAC systems account for the majority of home energy consumption [8,9], and the national energy efficiency action plan has measures used to achieve final energy savings in the period 2019–2021. One of them is the use of Solar rooftop power plants, which saves 20.6 (ktoe) annually [9].

Huge numbers of buildings throughout the world have old, constructed roofs that are poorly insulated but have plenty of surface area that might provide significant renewable energy through solar energy, which reduces energy consumption. Photovoltaic (PV) panels are frequently retrofitted into existing structures as renovating existing buildings to reduce energy use is a key goal for mitigating climate change worldwide, regardless of their thermal integrity. Roofs, on the other hand, require periodic repairs because of weathering throughout their useful lives. The building envelope hence acts as an important communication channel between the building and its surroundings, whether this is perceived climatic change or intangible cultural patrimony. Therefore, at some point, the integration of energy efficiency strategies with renewable energy has become essential at different levels.

Desert countries, such as the United Arab Emirates (UAE), are implementing policies based on fully glazed constructions while neglecting climate change. Consequently, the efficiency of the structure diminishes, and identification concerns arise. Thus, any responsive strategy should attempt to minimize excessive sun exposure while increasing the amount of sunlight available. Decreasing structural energy consumption, which is an efficient tool to minimize greenhouse gas emissions, is a sustainable development strategy that adapts and responds to climate change. In addition to the current situation, the authors of one study proposed and assessed nine possibilities for a modern style building at Ajman University in the UAE. The aim was to alter and renovate such buildings to derive optimum innovative solutions for enhancing daylighting and energy performance. The nine alternatives were analyzed using Revit and Insight 360 simulation software, which yielded the following results: the current scenario consumes the most energy (410 kWh/m^2/yr.). Scenario 8 proposes using PV solar energy as a shading tool occupying 90% of the total roof area to accomplish the lowest energy consumption of the building, occupant comfort, and energy efficiency while adjusting the operation schedule and window-to-wall ratio [10].

Hot areas worldwide, such as the UAE and Saudi Arabia, are gulf countries characterized by a dry hot climate. Consequently, buildings in these countries use more energy to keep their residents comfortable. PV has the double effect mentioned earlier; therefore, it is ideal for designing net-zero energy buildings in hot areas. The engineering college at Majmaah University in Riyadh was considered a case study. The authors performed a comprehensive simulation to investigate the best tilt angle of PV to generate electricity and provide optimum shade. In addition, the distance between PV arrays was measured to assess the effect on shading losses and the cooling load required. It was found that at 0.75 m between PV arrays, the net cooling load, and thus savings, was the highest, which means the cooling load required by the building was the lowest. Furthermore, the PV output at this distance was the highest, although the PV shading losses were the largest. However, building-integrated PV poses some challenges that should be considered in the early stages of design: partial shading, excessive heat in hot climates that reduces the efficiency of PV, and dust deposition on PV panels [11].

Moreover, shading losses result from the insufficient spacing of PV modules, dirt and dust, and adjacent building components or vegetation. These must be avoided by selecting the best installation space for PV arrays, taking into consideration site conditions and building configurations, and by using regular dust-cleaning techniques [12]. In addition, excessive heat also forms a challenge, but it can be solved by a proper cooling mechanism [11].

In another study, two proposed scenarios were studied: PV inclination and PV area. Firstly, PV inclination was examined horizontally and inclined at a tilt angle of 30°. The simulation demonstrated that PV inclined at such an angle yielded the best results; it has an annual daily insolation of 4.6 kWh/m^2, while horizontally installed solar panels have an annual daily insolation of 4.3 kWh/m^2 [12]. The PV area was estimated in two ways; the first assumed that the whole load can be met by the PV, while the second assumption was that the peak load only can be met by PV.

Orienting the PV panels at the optimum tilt angle is critical due to the varying weather conditions of each season. Although each season has an optimum tilt angle, it would be costly to purchase a sun tracker. A compromise fixed tilt angle is therefore the best solution to consider. A sustainable building located in Jordan, Amman, was simulated using MATLAB software to test the most suitable tilt angle of the PV panels. The energy gain resulting from the simulation process in monthly, quarterly, biannual, and annual periods for determining the optimum tilt angle was as follows: the optimization each month demonstrated that the tilt angle should be between 7 and 51° for each month in the year, the quarterly tilt angle optimization leads to a variation of 14–43° for each season, bi-annual results indicate a variation of 15–45°, and a tilt angle of 26° for the entire year was the optimum inclination for the PV panels [13].

Furthermore, a study conducted on a commercial building in a temperate climate in various cities in France with a usable floor area of 1296 m^2 proposed a feasible decision-making framework for passive cooling design in highly urbanized areas. Dissatisfaction with summer heat influences the normal passive cooling design for non-cooled structures in temperate areas, as well as fossil energy and greenhouse gas savings on a global scale. Passive cooling strategies for the indoor environment, on the other hand, can be beneficial for the local environment. Air-conditioned roofs, night-time air circulation, and rooftop PV panels as shading components were among the passive cooling methods investigated. The projected slanted PV panel installation occupied 43% of the rooftop area. The impacts of shading between panels were also properly considered. Occupant thermal comfort improved marginally in all climates when compared to the existing building; therefore, the indoor cooling capability is favorable but limited due to the roof insulation. Thus, solar panels as shading elements alleviate summer dissatisfaction while generating electricity, which improves energy efficiency in structures throughout the year [14].

By contrast, adding a PV system on high-albedo surfaces such as white tiled roofs may have little impact on the shading effect. In urban contexts, PV panels are extensively employed for on-site energy generation, particularly on roofs. Nevertheless, their use on roofs can have both favorable and unfavorable effects on structure heating and cooling energy requirements. When PV is placed on top of a highly reflecting (“white”) surface, the negative repercussions can be amplified. Based on the precise magnitude of the temperature of all associated components in a test building in Tempe, Arizona, research was conducted to examine these implications. The installation of PV on the white surface led to a slight reduction in calculated heat transfer rates at night [15].

Phase change material means that when a matter changes its physiological composition, from solid to liquid or the other way around, it captures or emits huge quantities of heat, known as ‘latent’ heat [16]. PCMs can be used on the outer walls, rooftop, ground floor, internal walls, and internal floor of a structure. PCMs are commonly used as an integral element in plasterboard, filling, concrete, and other construction materials, or as a covering element in building elements such as plaster. It is feasible to manage vertical and horizontal heat transfer by utilizing this material. The location of the PCM in a building component has an impact on energy consumption and occupant thermal comfort. PCMs can be encountered on the outer or interior surfaces, and in the central part, of construction elements such as concrete and masonry. They can be in the front or rear of insulation materials if they are integrated into them, forming a barrier [17]. In Riyadh, a phase change material was used to reduce energy demand in the building, taking into consideration the harsh weather situation in Riyadh. The analysis included the room temperature investigation, phase change material thickness, and the value of reduction or increment in heat transfer measured with the energy savings. The results showed that phase change in the roof decreases heat exchange from 1982 to 1291, which is identical to 34.9% diminution, or energy-saving by 691 kWh [18].

As the years are passing and the climate change problem is increasing, there should be a way to handle this effect. The building sector consumes a lot of energy all around the world, and the concept of NZEB is a very upcoming concept that needs to be implemented widely; the use of renewable energy and the active energy systems are considered to be in alignment with adopting the concept of NZEB. An investigation was conducted using a commercial program for estimating heating and cooling loads, and a thorough techno-economic possibility evaluation of a new small independent home (with a total area of roughly 100 m^2) was conducted in Amman (HAP). For this goal, a specially designed program to assess the techno-economic viability was built. Electricity and heating energy for this home were entirely sourced from solar energy. As a result, gaseous emissions, including GHG, were greatly decreased. It was discovered that employing a suitable energy storage system eliminated the need to purchase fuel for heating or draw electricity from the grid. With a payback period of roughly 8 years, the anticipated monthly savings in energy costs might approach JOD 260 [19].

Also, another study concentrated on a variety of variables, such as orientation, layout, type of insulation, type of windows, shading devices, and type of ductwork, which used a comprehensive and detailed model of the natural convection air-cooled condenser integrated to stack (NCACC) as a highly innovative ventilation method. The study investigated the economic and computational potential of various integrated passive and active design systems for the Jordanian residential building sector. To create a Near Net Zero Energy Building (nNZEB) in Irbid, Jordan, this study employs three building sustainability assessment methodologies. Facility performance analysis could be identified using one of two methods: computational or analytical. To find the optimal building energy model, a dynamic building energy modeling and simulation software with various climatic circumstances was used. The payback period for each of the implemented systems was estimated using a suitable financial criterion [20].

Moreover, a study used an integrated approach to envelope retrofitting by blending energy-efficient and financially viable retrofitting possibilities, based on an analysis of the suggested envelope retrofitting alternatives' prospective energy savings and beginning costs. The study used a mixed-approaches design approach that combined qualitative and quantitative techniques. These techniques included field monitoring of environmental parameters inside schools, questionnaires, national records, and physical assessments. The basic payback period analysis method was used for financial evaluation and energy simulation. The effectiveness of envelope retrofitting was evaluated using the results of the research methodologies, both before and after its implementation. The results showed that the suggested envelope retrofitting strategy resulted in energy savings of up to 54% with a payback period of 5.5 years [21].When an investigation was performed on the Jordan University of Science and Technology campus located in Jordan, considering the energy and economic analysis of 5 MWp photovoltaic system influenced by the climatic circumstances, the economic analysis findings showed that the annual internal rate of return was 30.11% and the pay-back period was 4.32 years [22]. Finally, research was conducted on a residential house in Amman, Jordan, considering the economic benefits of installing the PV system, since it had been in place for four years. The system has been inspected to assess its effectiveness. The maximum output of this system is 3 kW/h, which is the permitted load established by Jordan's electrical board. The system generated 24,000 kW in total throughout the four years that were under observation, or 6000 kW annually and 500 kW monthly. A usage of 1500 kW/month offers the best savings for a 3 kW/h system, and if usage is higher, then more photovoltaic panels should be employed [23].

There are several techniques in terms of reducing heating and cooling loads, including insulation materials that are used in roofs, walls, and floors, natural ventilation types through openings, and different types of shading elements in the facades. On the other hand, the technique that we investigated in our research is not better than any of the above-mentioned techniques, but every method is considered for certain building envelope elements.

This research is one of its kind in the middle east region, as few studies have studied the effect of the photovoltaic system as a shading device for the uninsulated conventional roofs in Europe, the United States of America, and Asia. Moreover, the previous studies included the effect of PV on other types of roofs, and that is what makes this research unique in its field. In addition, this study covers a research gap that misses the indirect effect of the solar panels on the roof. The investigation of the shading effect of the uninsulated roofs will encourage people to install a photovoltaic system on their roofs, due to its double effect in generating electricity and shading the roof. Furthermore, it will reduce the cooling load, enhance the impact of the building sector on the environment, and minimize the energy consumption rates.

2. Methodology

This section explains the process that was implemented to enhance the roof thermal performance of an uninsulated residential unit in the Mafraq governate in the Hashemite Kingdom of Jordan. Integrated Environmental Solution-Virtual Environment and Revit (version 2020) software was applied to enhance the building's energy performance by calculating the thermal behavior of typical Jordanian dwellings. This investigation focused on measuring the thermodynamic efficiency of a typical residential structure that fulfills Jordanian building code thermal specifications, explaining the structure envelope design restrictions that require improvement, and developing the design variables using a process that includes executing multiple simulations to reach the best outcome. This study thus considered the thermal performance of PV panels as a shading system on traditional poorly insulated rooftops on a domestic standard size house with the ideal tilt angle for minimizing total energy demand [24].

2.1. Research Area and Climate Zone

Jordan is situated in the West Asia region and has an arid to semi-dry climate with a mean annual rainfall of fewer than 50 mm in most locations [25]. It is a small-sized Middle Eastern country with an area of 89.34 km^2. The Dead Sea runs along its western edge, while the nation has a 26-km shoreline to the southwest with the Red Sea. The country's terrain is extremely varied, ranging from almost 400 m beneath sea level at the Dead Sea to 1.85 m above sea level (asl) at the southernmost borderline at Um Addams Hill [26]. The climate in Jordan varies greatly, as it is a warm Mediterranean climate with mild, rainy winters and hot, dry summers. Moreover, winter lasts from December until early March. It has four different seasons, with winter and spring being relatively brief, and summers being lengthy, dry, and exceptionally hot. Because of the low humidity, even temperatures in the low thirties are tolerable. Jordan does not experience the same intense heat as the Gulf countries, with temperatures rarely exceeding 35 °C even in the height of summer [27].

Jordan, despite its tiny size, is divided into three separate climate zones. The most extensive of these is, of course, the desert, which encompasses more than 80% of the country. Most cities, towns, and archaeological sites are in the western mountain ranges, whereas the Jordan Valley, which is roughly 300 m below sea level, has a completely different climate from the rest of the country [28]. In the highlands, the nights are relatively cool. On average, daily temperatures in Jordan reach around 30 °C or higher. The south has the greatest average temperatures, ranging from 37 to 41 °C. The months of July and August are the warmest and driest, as Jordan has an annual average of 310 days of sunshine [28]. In summary, Jordan experiences hot, dry summers and rainy, freezing winters [27]. As shown in the Thermal Insulation Code [29], the region can be split into four main climate zones that are separated laterally: The Rift Jordan Valley zone, the mountain chains spanning from north to south, the central region of Jordan, and the desert plains [30]. Jordan's semi-arid desert region in the east encompasses a substantial portion of the country. During the day and evening, as well as in the summer and winter seasons, the weather varies dramatically.

Summers are hot, arid, and breezy, with peaks of 40 °C, while winters are extremely cold, humid, and windy.

Mafraq is in the Mafraq Governorate's western province and is situated in the Sahara–Arabian climate zone, which covers the desert plains. It is situated at 36.1° east longitude and 32.2° north latitude. This site has a mean annual temperature of 16.6 °C and receives 5.5 to 6 kWh/m^2 of solar radiation each day [31]. Mafraq and Amman are approximately 65 km apart. Syria to the north, Iraq to the east, and Saudi Arabia to the south are the nations that share its boundaries. Mafraq and its suburbs (Greater Mafraq) occupy a total area of one hundred square kilometers, with around forty square kilometers of urbanized space. Mafraq city covers a total area of twenty-six square kilometers; however, only eleven square kilometers are structured. The city's terrain is flat, with just a few ups and downs. The altitude varies between 675 and 750 m above water level. Mafraq's climate, as shown in Figure 1, is classified as semi-desert, with heated, dry weather in the summer and bitterly cold temperatures in the winter. Summer, which begins in May and finishes in September, and winter, which starts in November and finishes by the end of April, are the two major seasons in the city. August has the highest monthly mean temperature of 32.6 °C, while January has the lowest recorded mean temperature of 2 °C, with a yearly mean temperature of 18 °C. In addition, the city has a 36% average relative humidity. It also has the country's minimum annual precipitation of less than 150 mm [32]. The meteorological station is in Mafraq city, which is situated at 32.36 N and 36.26 E [33] in the north of Amman.

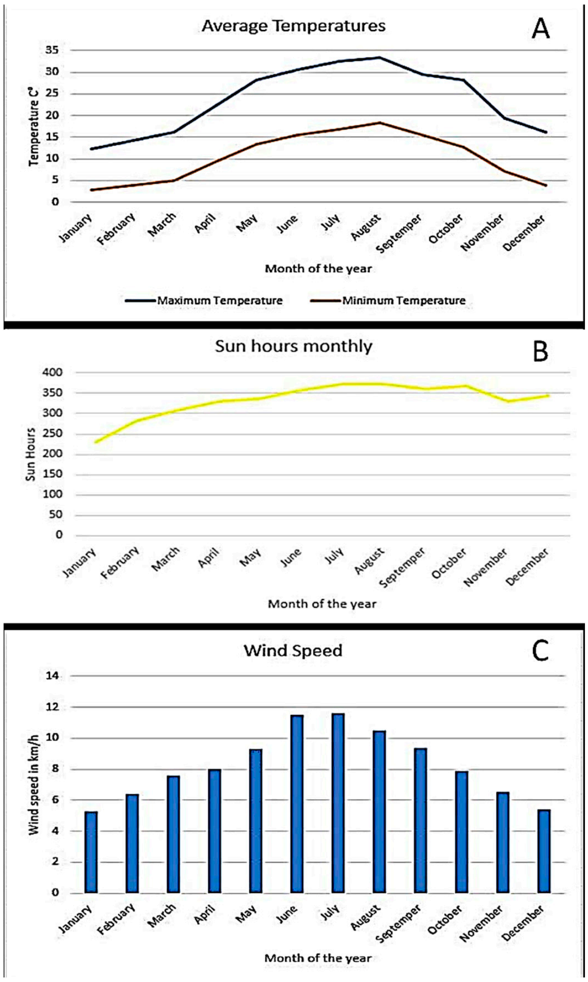
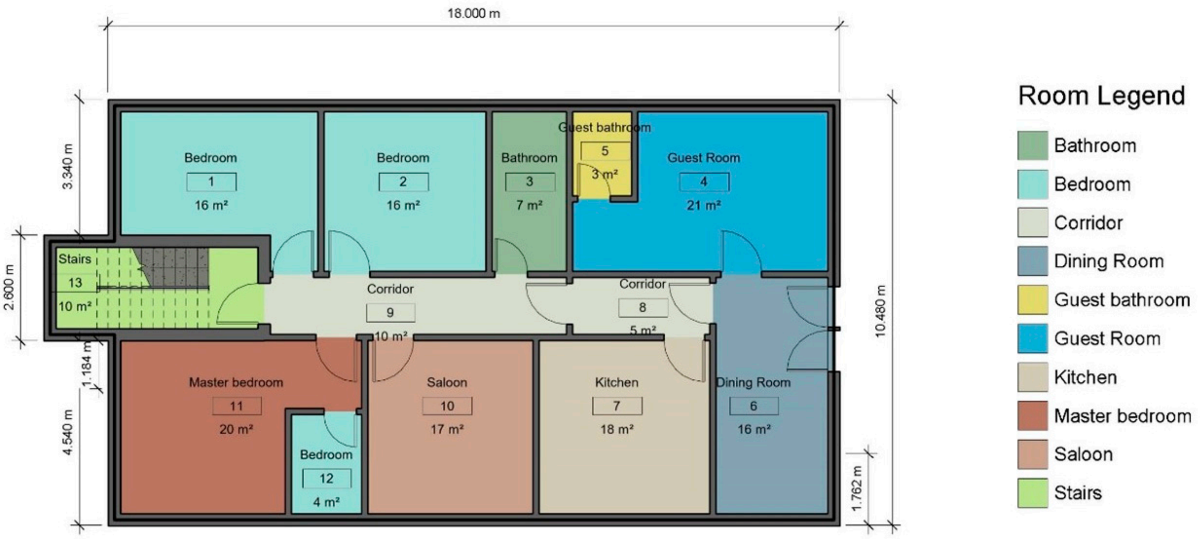


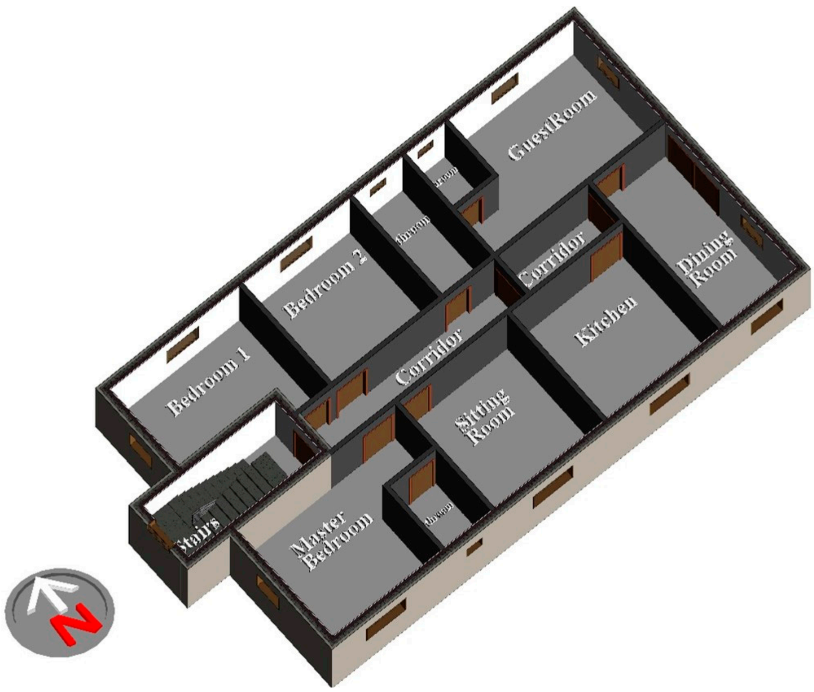
Figure 1. Main Climate parameters in Mafraq city in the year of 2021: (**A**) average minimum and maximum temperature, (**B**) sun hours, and (**C**) wind speed.

2.2. Description of the Prototypical Base Model

The baseline simulation model was modelled using Autodesk Revit (version) 2020 software (Revit is a commercial building information modeling (BIM) software by the company Autodesk—an American multinational software corporation, San Rafael, CA, USA). While the thermal properties, construction details, and material properties were assigned using IES-VE simulation software. The average family house is used as a reference design; this has a rectangular shape, and the long axis of the building is facing the south with a total length of 18 m, and the short axis with a total length of 10.50 m as shown in Figure 2.



(**A**)



(**B**)

Figure 2. Traditional one-floor-height domestic building. (**A**) Architectural Plan. (**B**) Three-dimensional view.

This is a traditional one-floor-height domestic building with a total area of 180 m^2 that comprises a sitting room (saloon) with an area of 17 m^2, guestroom with an area of 21 m^2, food preparation area of 18 m^2, three bathrooms with an area for each 3, 4, and 5 m^2, main bedroom with an area of 20 m^2, two bedrooms with an area for each 16 m^2, a dining room with an area of 16 m^2, and stairs with 20 risers. As depicted in Figure 3, each of the spaces was classified as a recognizable area, while window to wall ratio varies depending on the space function of each room from 12.5 to 16%.

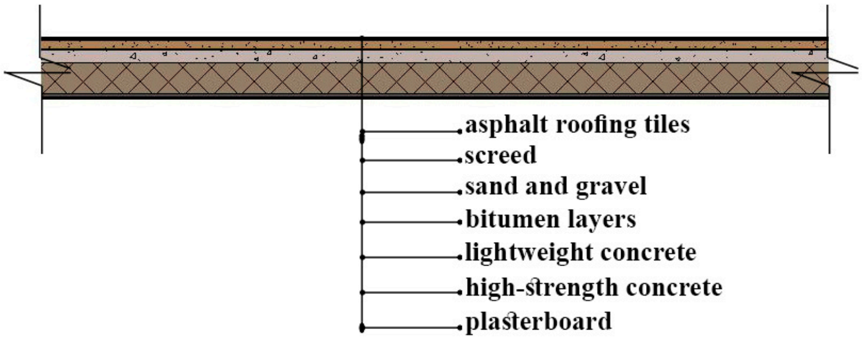


Figure 3. Roof construction layers.

The construction substances used in building the structure and its parameters were taken from a standard architectural design prototype that relates to Jordanian building codes, and were assigned to the project in the simulation program as follows in Table 1, and each construction element is clarified with its own layers on Figures 3–5.

Table 1. Construction layers, U-value, R-value, and K-value.

The Constructed Element	Construction Layers	Thickness (m)	Thermal Transmittance (U-Value)	Insulation (R-Value)	Thermal Conductivity (K-Value)
Roof	Reinforced concrete, mortar, sand, and gravel; structural low-density concrete, roofing tiles; bitumen layers; and plastering	0.36	2.04 W/m^2·K	0.49 K·m^2/W	0.73 W/K ·m
Floor	Reinforced concrete with gravel and a soil layer covered by mortar and ceramic flooring tiles.	0.225	1.2827 W/m^2·K	0.78 K·m^2/W	0.29 W/K ·m
Exterior walls	stone, reinforced concrete, thermal barrier; a layer of plastering and a layer of aerated brick blocks	0.40	0.28 W/m^2·K	3.57 K·m^2/W	0.12 W/K·m
Interior walls	masonry blocks with gypsum board plastering on both sides	0.125	1.87 W/m^2·K	0.54 K·m^2/W	0.23 W/K·m
Glazing	Double glazing of 6 mm is used and 13 mm air (thermal barrier).	0.025	2.7834 W/m^2·K	0.36 K·m^2/W	0.070 W/K·m
Frame	The glazing of external windows was encased in a thermally fractured frame made of aluminum.		2.98 W/m^2·K	0.34 K·m^2/W	0.015 W/K·m

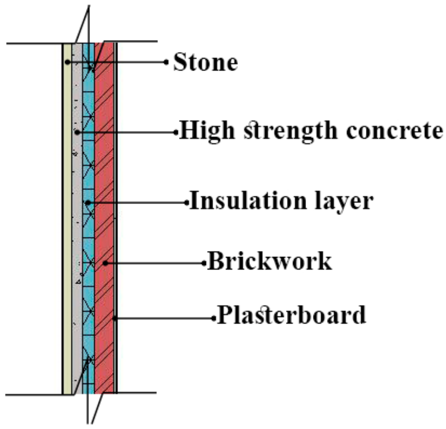


Figure 4. External wall construction layers.

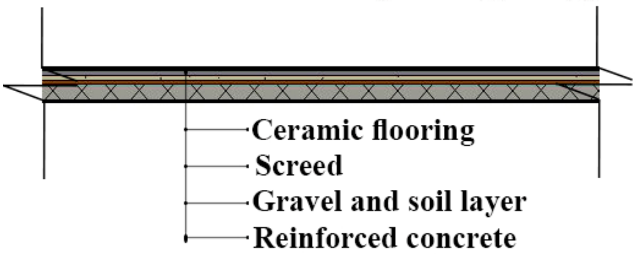


Figure 5. Base ground floor construction layers.

The research was conducted using the IES-VE program and REVIT (version 2020) to determine the thermal impact of solar panels as a shading device on the structure's cooling requirements and overall energy consumption. Using data from the closest meteorological station, the computed baseline model depicted a moderate-income residential unit in Amman, Jordan. The heating and cooling operations of the house were calculated in kWh/month, and annual heating and cooling energy reductions for the baseline and updated models were also calculated.

2.3. Modeling and Simulation Procedure

Integrated Environmental Solutions-Virtual Environment (or IES-VE) was chosen as the simulation software to analyze the thermal behavior of the structure [34]. This is due to its well-established popularity and its wide utilization among investigators, educators, architects, and engineers as an integrated energy assessment platform for the formation and renovation of dwellings. It is known for transforming complicated thermal arithmetic operations into easy-to-understand technical specifications and modeling. IES systems have evolved from sustaining small buildings to reaching the level of a city (IESVE, version 2017, (Integrated Environmental Solutions (IES) Virtual Environment (VE) is a software and consultancy company headquarter located Glasgow, Scotland, UK)). Its computation procedure has been broadly affirmed as fulfilling the criteria of regional and global guidelines, such as The American Society of Heating, Refrigerating and Air-Conditioning Engineers is an American professional association seeking to advance heating, ventilation, air conditioning and refrigeration systems design and construction for instance ASHRAE Standard 140 (standard method of test for the evaluation of building energy analysis) [35], USGBC (LEED Automation Partner), UK National Calculation Methodology (NCM), ASHRAE 55 calculation procedure, and ISO 7730 [36] calculation procedure (IESVE, 2018) [30]. A comparison of several simulation tools identified IES-VE as one of the most effective and productive simulation tools assisting engineers in the evaluation of diverse construction systems. The information handling capacity of the application is the other major issue to consider. It meets the demand for fast and precise evaluations for many options, while also ensuring the nature of simulation results. The program allows easy access and enhancement in the measurement of thermodynamic performance, enabling rapid replies at the beginning of the design phase and an analytical approach in the subsequent stages of design [37]. IES-VE's simulation program has been enhanced and upgraded. A comprehensive behavior tool with integrated capabilities is included in this application. As a result, the software can sustain extensive thermal and natural lighting data as well as conduct other ecological evaluations. Because the finished design process and environmental data analysis are visually attractive, and have a broad set of performance analytical techniques encompassing solar, energy, and lighting data, time and money, egress, computer modeling, and mechanical measurements, it is well-suited to the objectives of this paper. IES-VE is composed of numerous elements [38].

Revit software (version 2020) was used for modeling the structure and for the solar analysis. Autodesk Revit is a Building Information Modeling (BIM) software that assists engineers, architects, MEP engineers, and constructors with building information modeling [39]. Architects use Autodesk Revit Architecture to generate architectural models, as this technology has slowly evolved from CAD (computer-aided design) to BIM over the previous decade [40]. It enables customers to create a 3D model of the structure and its elements, annotate the model with 2D drawing elements, and acquire building information from the database of the construction project. Revit is smart enough to plan and monitor all phases of the lifecycle of the building from design to construction and deconstruction [39]. A three-dimensional Revit model was used to depict the gathered information needed to complete the computation. This prepares the building elements to be tangible and rational, which aids architects and users in making the best strategic choices. The structure's depiction of the spatial location and orientation of a house gives consumers ideas for shading, sustenance, and gardening. The peak cooling and heating demands, the capabilities of devices required to adjust the designated construction, the shares of each element of the facility, including the roof, walls, windows, skylight, ventilation, and infiltration, and the expense of conditioning loads become simple to specify. This aids architects in understanding how parts of the building lose energy and which elements are the largest consumers of energy [41].

To evaluate the effect of PV panels, on uninsulated rooftops, as a shading device, the following procedure was taken in IES-VE software. The procedure contains the described below steps:

1. Modelling the baseline house using Revit software.
2. PV panels were constructed in the IES-VE program, as topographical shading.
3. The input of weather data by choosing the weathering profile of the specified location-Mafraq city.
4. Input data that includes heating and cooling setpoints at 20 °C and 26 °C, respectively; the heating and cooling systems were chosen as the split system for cooling while central heating with radiators was chosen for heating, and an occupancy schedule was determined too.
5. A vast number of simulation processes were performed to generate applicable results for heating and cooling loads. Moreover, the Apache simulation tool was used in the IESVE program results.
6. The data results were in kWh
7. The data were managed and plotted in the Excel software as figures with heating and cooling bars in kWh through the whole year for Mafraq city.

The baseline, developed model was simulated under these assumptions and boundary conditions:

Assumption 1. *The ground temperature for the developed model is 13 °C.*

Assumption 2. *The internal heat gains for the model consist of occupancy, lighting system, electrical devices, and hot water circulation.*

Assumption 3. *The indoor set-point temperatures are fixed at 20 and 26 °C in the winter and summer, respectively.*

Assumption 4. *Heating hours through the year: 777.6 h, and cooling hours through the year: 600 h.*

Assumption 5. *Heating and cooling systems were the same in each software, as it was chosen split system for cooling while central heating with radiators was chosen for heating.*

Boundary condition a: T-inside is 20 °C in winter, 26 °C in summer.

Boundary condition b: T-outside varies all the time, but the average, minimum, and maximum temperatures are clarified in Figure 2 for the studied area.

2.4. Photovoltaics Specifications and Integration with the Building Rooftop

The transmitted heat was reduced by installing a solar panel as a shading system. This optimization procedure was undertaken to quickly analyze and select design ideas that improve the energy demands of the decision variables. The solar array canopied 11.3% of the house's top floor space, enabling it to comply with natural daylight regulations while also leaving room for future rooftop installations and other prohibitions that already exist in most Jordanian traditional homes and multi-level housing units, such as storage tanks, heating and cooling package units, satellite dishes, aircon cooling systems, and steam engines, as well as ease of access restrictions, parapet walls, staircase, and columns. Roof plan design: located near to wall (1 m), inter-row spacing, structural and shading limitations. The structure has 4.50 kW of total power capacity, as every solar panel with an area of 1.70 m^2 produces a range of power of 300–380 Watt according to Clean Energy Reviews Website, and 12 panels are used in this research as mentioned above. Moreover, the characteristics, materials and layers of the PV panels were made according to previous research [1].

Coverings built of PV panels can better dissipate heat and make maintenance easier. A roof with a mounted photovoltaic panel often experiences a combination of convection, radiation, and heat conduction. The heat transfer process can be expressed as follows [42]:

$$\frac{\partial T}{\partial \tau} = \frac{\lambda_n \partial^2 T}{\rho_n C_n \partial x2} \tag{1}$$

where λ_n denotes the thermal conductivity of roof material in W/(m·K). or denotes the density of roof material in kg/m^3. C_n denotes the heat capacity of roof material in J/(kg·K).

The contributions from radiation and convection gain are subdivided into the overall amount of heat gain transmitted to the interior. In contrast to how heat received through radiation is transformed into the radiation cooling burden using the RTF, heat gained through convection is directly converted into the convection cooling load.

For the most popular rooftop-mounted PV, the following presumptions are made: Since the lateral dimensions of the PV modules and the roof are much larger than their thicknesses, the heat transfer through them is one-dimensional and has unsteady heat conduction. Additionally, there is enough space between the horizontally mounted PV modules and the roof to prevent thermal buildup beneath the PV modules. The high temperature of the back sheet in this installation circumstance creates a convective heat transfer boundary layer, but it has no effect on the roof's outer surface.

For the exposed roof, the cooling and heating of the upper surface drive the heat conduction through the roof. Under the tilted PV array, however, while heating from the top is dominant, heating from the bottom also occurs.

$$Q = \frac{k}{\Delta x}(T_{31} T_{32}) \tag{2}$$

where Δx is the numerical discretization distance between roof layers, k is the Thermal Conductivity, T_{31} is the hot temperature and T_{32} is the cold temperature [43].

2.5. Solar Energy Analysis before PV Installation

Prior to the installation of the solar panel, a yearly solar analysis was completed using Revit Building information modeling software (version 2020). The cumulative insolation was 1536 kWh/m^2 on the rooftop, see Figure 4.

2.6. Characteristics of PV Solar Panels

Monocrystalline silicon, a locally sourced panel feature, was selected as the solar panel for the analysis. This system was composed of PV panels dangling from the rooftop 0.45 m away from the parapet walls of the house. To minimize the shading effect of the panels upon each other, a horizontal divider was placed among them. Consequently, there was a 1.30 m space between the two lines of panels. There was a maximum of 12 PV panels on the rooftop of the dwelling, each measuring 1.70 × 1.00 m in size [44] as clarified in Figure 5.

With a net U-value of 6.87 W/m^2·K, a total thickness of 0.60 cm, and a net R-value of 0.0055 m^2·K/W, the solar panel module characteristics were inserted into the IES-VE computation program. The term "solar panels" refers to a type of glazed PV panel whose performance is determined by a constant global array efficiency. The thermal value of the unit affects overall efficiency. The portion of the energy generated is not considered. Various rotations and inclination angles were examined to determine the optimal angle for the strongest shade effect.

3. Results and Discussion

3.1. Base Building

This section describes the overall amount of energy and minimizations from a rooftop PV system placed as a shading device on a typical Jordanian home. The heat transfer performance of the reference module design was investigated and calculated as a reference point for the improved design model produced from the developed procedure. A conventional structure in Mafraq's cold, semi-dry climate will use 4530 kWh/year for heating and 1290 kWh/year for cooling, according to the simulation. The total heat transported from the rooftop to the internal environment of the building space was considered while calculating the cooling/heating load, with the core temperature of the building set to the optimal working point of 20 °C in the winter and 26 °C in the summer. The cooling months were May–October, and the heating months were November–April, according to the IESVE computation program. The primary idea is that although varied rates of adaptation and sunshine benefits are instances of thermal transfer techniques, HVAC systems can maintain the average temperature of the interior space at the set value. In both shaded and unshaded PV panel situations, the heat flow measured in W/m^2 flowed from the roofs to the inside area. To assess the impact of PV panels on the building's energy demand, conventional roof construction in Mafraq, Jordan [40] was used as a baseline scenario [36].

Most of the building's thermal simulation software is unable to predict the actual energy consumption of the building accurately and precisely due to many factors, such as different run engines for each software [38,39], the accuracy of the input, or default data such as the R-value, weather data and the sky temperature [42]. Many retrofitting approaches were used to improve the building's thermal performance and decrease energy consumption, even though, in some cases, a photovoltaic system will be a cheaper option than the retrofitting [43–45].The inside temperature was set and assumed to be 20 °C in winter, and 26 °C in summer, while the outside temperature is not fixed and varies all the time, as the weather station that is mentioned and used in the simulation has its own data for the temperature in the studied location.

3.1.1. Cooling Load

Cooling loads were computed to be 1290 kWh/year, according to the computed proposed base model, with the maximum values in July and August, as illustrated in Figure 6.

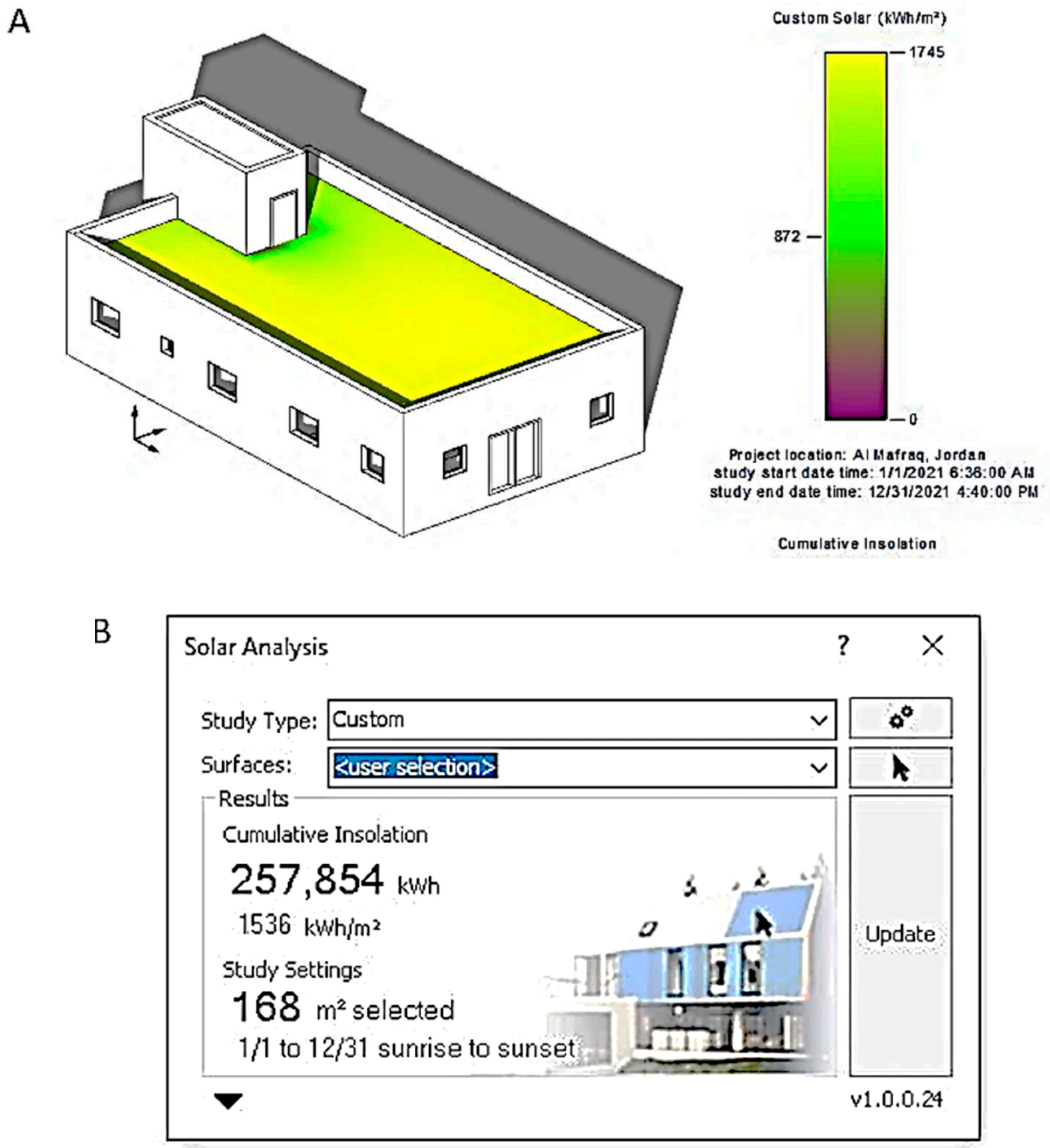


Figure 6. (**A**) The three-dimensional prototype house design with solar radiation analysis before PV installation, (**B**) The Annual Cumulative Insulation in kWh/m^2 on the uninsulated roof prior to the installation of the PV system.

3.1.2. Heating Load

Heating loads were computed to be 4530 kWh/year, according to the computed proposed base model, with the largest values in January, February, and December, as illustrated in Figure 6.

3.2. The Improved Procedure

Based on the results, an intermediate solution between the summer and winter angle of inclination was determined. The south orientation with an acceptable inclination angle of 30°, as well as an orientation balanced with a 0° incident angle, were best for retaining the maximal shade benefit.

3.2.1. Cooling Load

In accordance with the computed optimum design, cooling loads were estimated every year after the renewable power was installed; the cooling load decreased to 1130 kWh/year, while the peak values in July and August also decreased, as depicted in Figure 7.

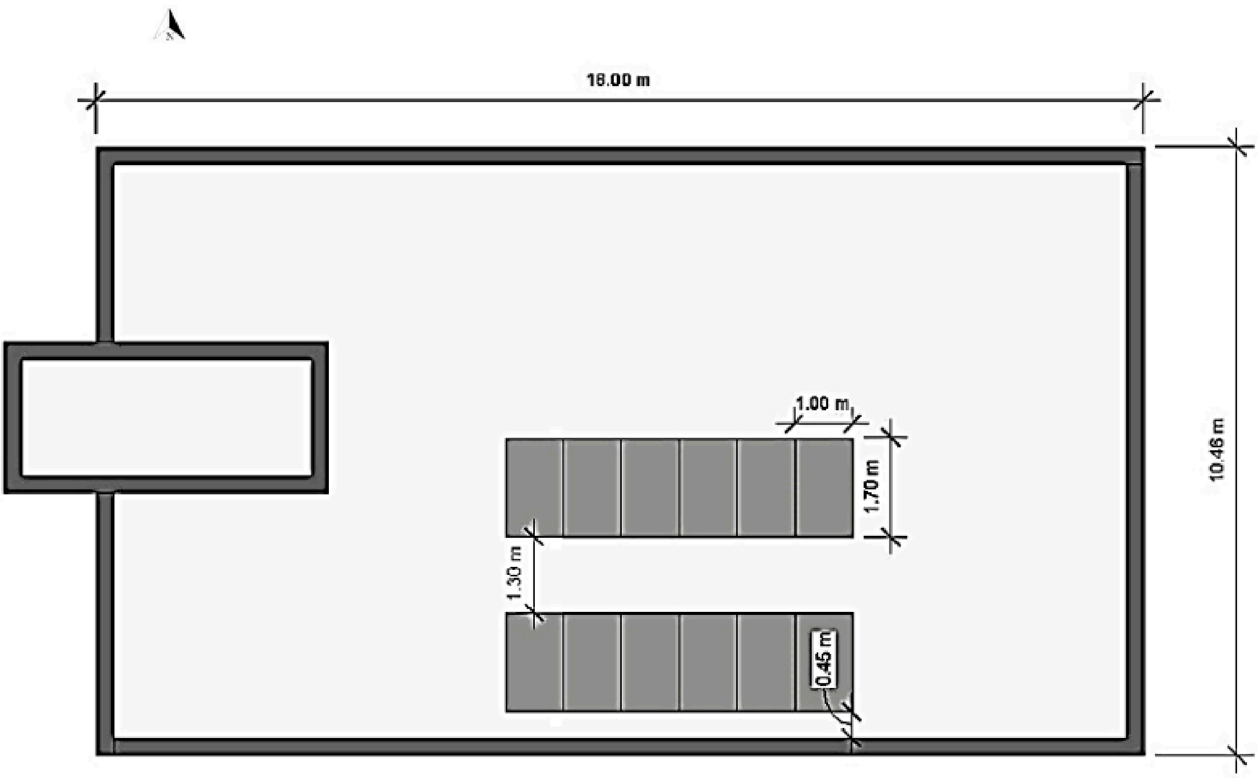


Figure 7. The rooftop plan layout after the installation of the 12 solar panels.

3.2.2. Heating Load

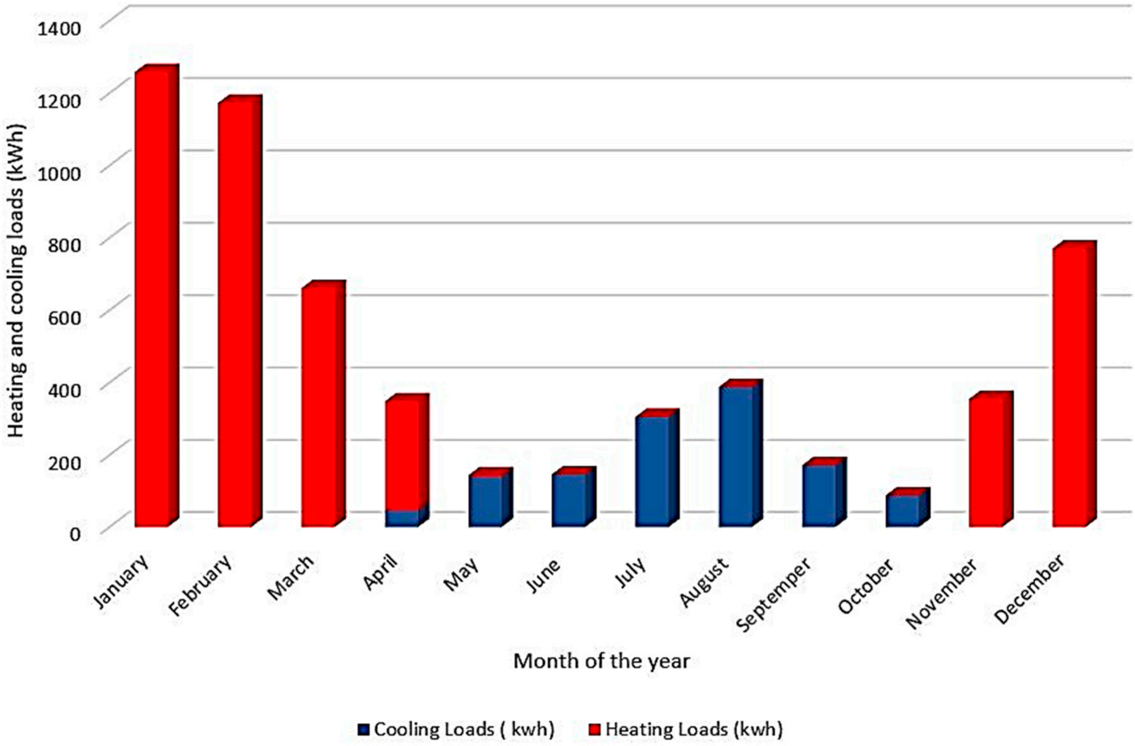
In accordance with the computed optimal design, heating loads were computed every year after the renewable power was installed; the heating load increased to 4720 kWh/year, as presented in Figure 7.

Using PV system as a shading device reduced the cooling loads by 5.54%, while the heating loads increased by 4.85%. On the other hand, other studies used phase change material in roofs to reduce energy demand in the building; the results of such research found out that the heat exchange was decreased by 34.9%. In our research, the indirect effect of solar panels is studied to ensure that renewable energy has many benefits, and to draw the attention of this indirect one, as the direct effect of generating electricity is already known, but to encourage people of using renewable energy, it was important to study its second effect on the roof surface of the buildings.

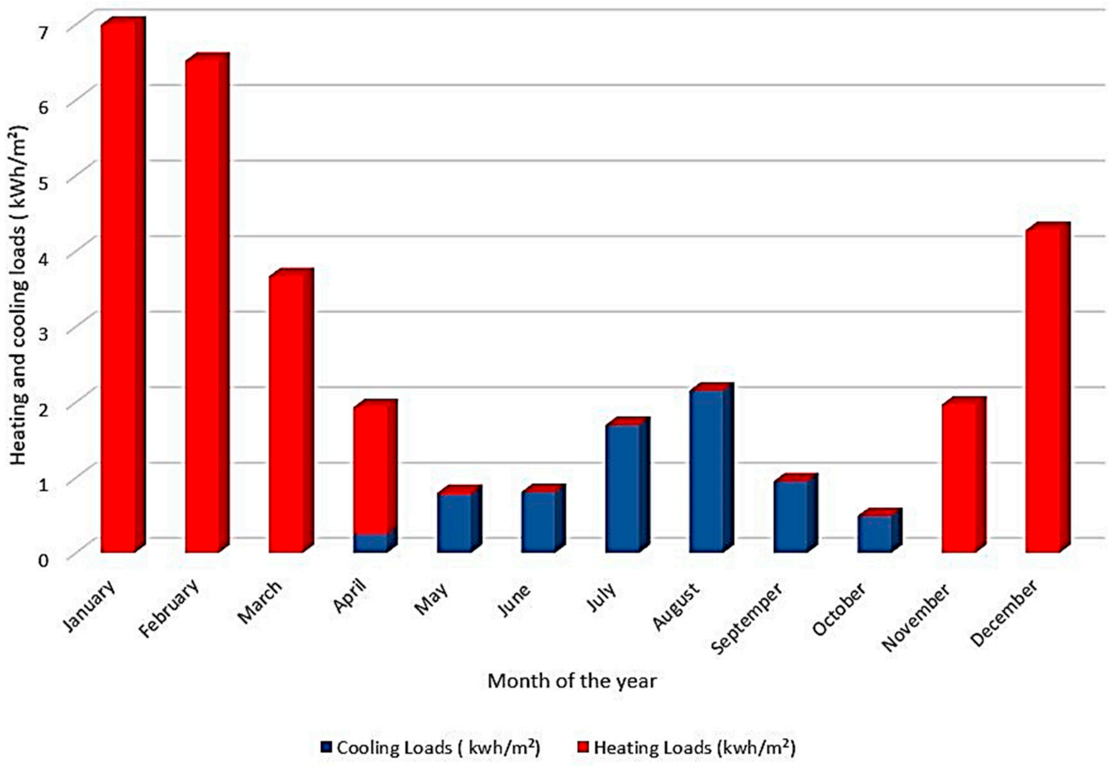
3.3. Solar Energy Analysis after PV Installation

Annual Solar Analysis was implemented using REVIT (version 2020) following the installation of PV.

The Cumulative Insulation was 190.02 kWh, which equates to 1132 kWh/m^2, as illustrated in Figure 8 and the monthly cooling and heating loads in the developed design in Mafraq city for one year in Figure 9. PV will shade the building as shown in Figure 10.

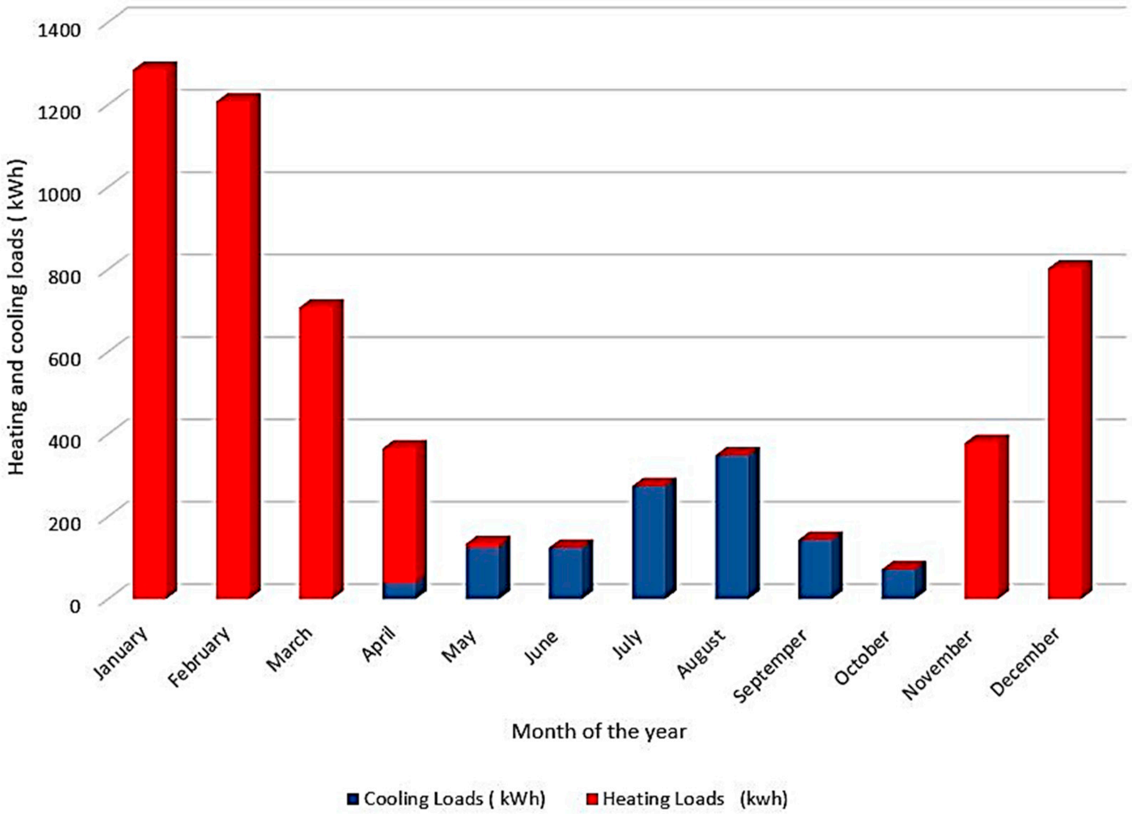


(**A**)

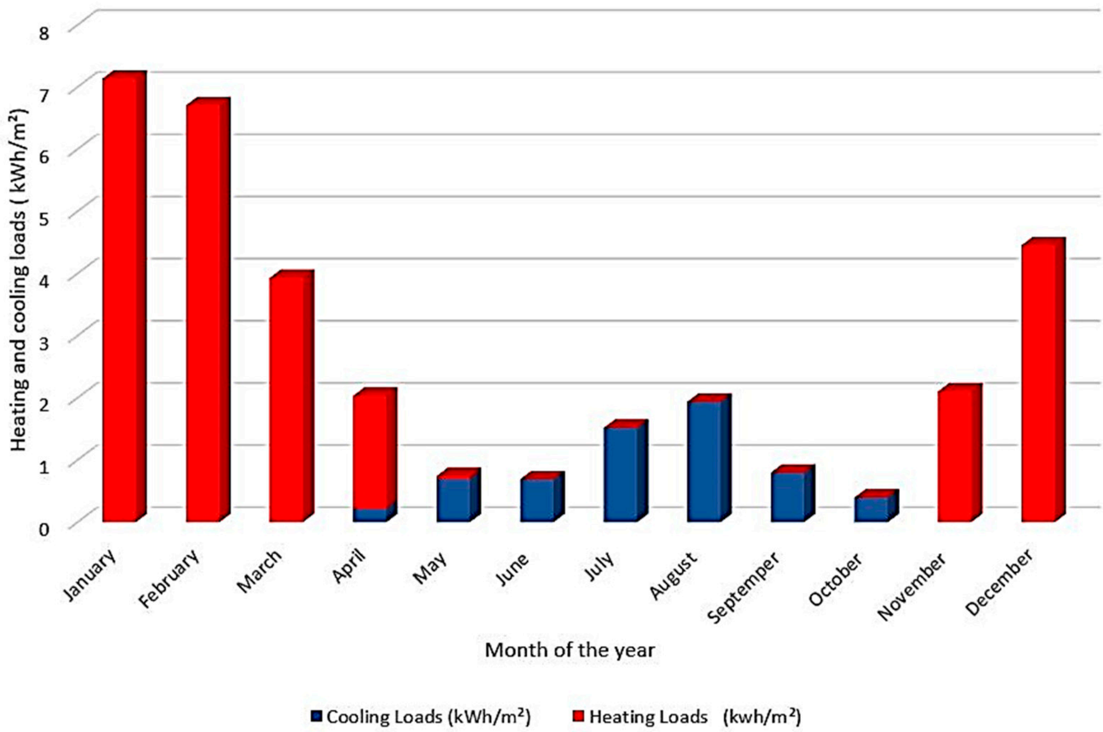


(**B**)

Figure 8. (**A**) Monthly cooling and heating loads in the baseline model design in Mafraq city for the year 2021, (**B**) Monthly cooling and heating loads per m^2 for the year 2021.

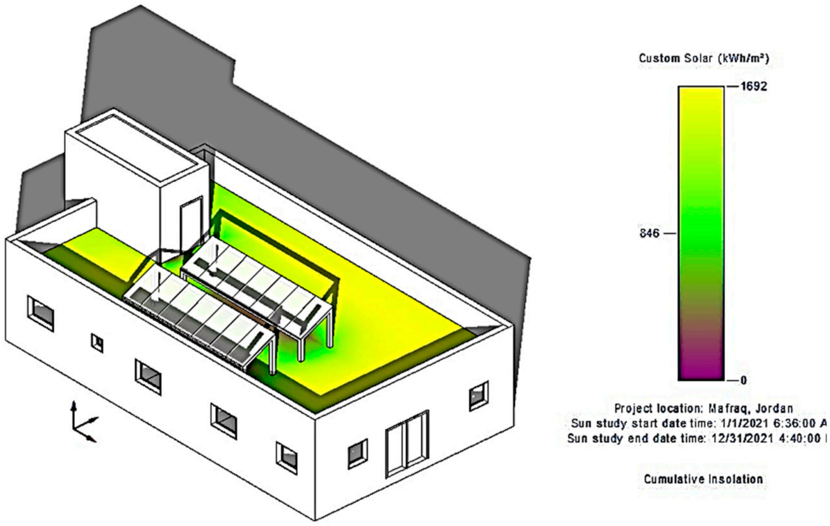


(**A**)

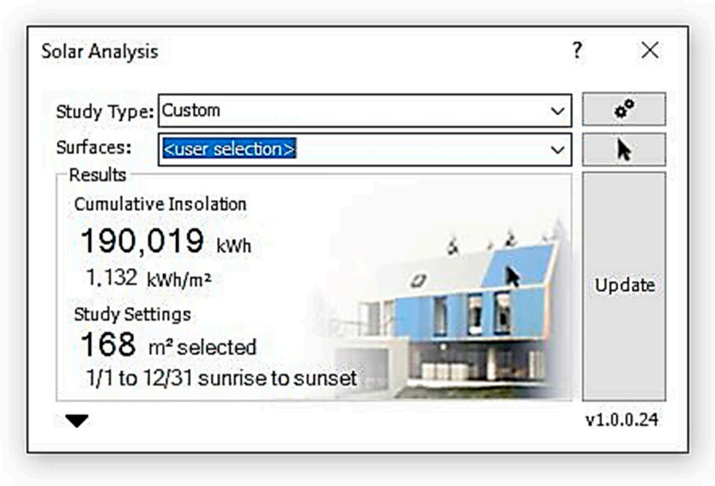


(**B**)

Figure 9. (**A**) Monthly cooling and heating loads in the developed design in Mafraq city for the year 2021, (**B**) Monthly cooling and heating loads per m^2 for the year 2021.



(**A**)



(**B**)

Figure 10. After PV installation. (**A**) The three-dimensional view of the building. (**B**) The Annual Cumulative Insulation in kWh/m^2.

4. Total Energy Involved in the PV System

The energy computation approach for the guideline model (with an area of 180 m^2) yielded an overall energy requirement of 5820 kWh/yr., consisting of cooling and heating loads. The power created by tilted OV systems inside the extractable region can be used to reduce the annual cost of the model's yearly energy consumption rate; however, the electric power of solar panels was not considered in this work. The involvement of PV electricity increases as the usable area increases, as does the shading benefit, resulting in a higher decline in cooling loads due to the direct and indirect advantages of solar panels.

5. Validation

The input data of the analyzed model were taken from local reliable Jordanian building codes for the current construction situation. The output results were approximately the same as familiar research that was conducted in a similar climate zone for a similar building design. Moreover, the simulation process was tested also in another simulation program (Design Builder). Therefore, the outcomes were in line with the stated results of the IESVE program. The results of the two simulation programs are as follow as shown in Table 2.

Table 2. The results of the two simulation programs.

Software Used	**Before the Installation of PV Panels**				**After the Installation of PV Panels**			
Heating/Cooling Loads	Heating Load before (kWh/Year)	Heating Load before (kWh/m^2/Year)	Cooling Load before (kWh/Year)	Cooling Load before (kWh/m^2/Year)	Heating Load after (kWh/Year)	Heating Load after (kWh/m^2/Year)	Cooling Load after (kWh/Year)	Cooling Load after (kWh/m^2/Year)
IES-VE	4530	25	1290	7	4720	26	1130	6.3
Design-builder	3540	20	1420	7.9	3930	22	1350	7.5

6. Conclusions

To minimize emissions of greenhouse gases, structural refurbishment to increase efficiency is immensely important. A complete analysis of the efficiency improvements that may be realized by integrating the uninsulated roof with solar power generation as a shading device was performed. How this factor can be adjusted to improve the energy efficiency of several housing construction models is examined. The overhanging shading of solar and long-wave roof radiation associated with stand-off PV panels was estimated for the first time as part of the assessment.

The objective of this study was to assess how the PV system installed on the rooftop of a typical Jordanian house affects the uninsulated roof concerning heating and cooling demands in a climate zone of Mafraq City. Our research for Mafraq, Jordan, presents coherent evidence for making roof retrofit selections by combining PV installation with natural rooftop involvement (retrofitting during roof repair) or rooftop energy-related enhancement (re-roofing). We calculated the ideal tilt angle, the capacity of a PV system that can accommodate traditional structures, and the relationship between these variables and yearly energy usage.

The PV rooftop modules were designed as part of a transient-state 3D dispersed thermal model. The analysis focused on an intermediate dwelling in Amman, Jordan's capital. The restrictions placed on the utilization of PV by building rooftops were also explored.

To conclude, five main results were highlighted:

- The total energy consumption of a baseline model was calculated to be 7578.5 kWh/year, with the heating load accounting for 4132.9 kWh/year and the cooling load accounting for 3445.6 kWh/year.
- The data demonstrated a 4.85% increase in heating demand through the roof in the winter, increasing the equivalent electrical demand for interior heating.
- During the cooling months, a 5.54% decrease in cooling demand was evident, reducing the energy consumption for inside cooling.
- The results underscore the purpose of this work and can be used as the basis for suggestions to energy officials, the construction industry, and consumers. A rooftop solar panel also gives a deeper understanding of the HVAC energy demand fluctuation in facilities, which is important in the current construction situation.
- The idea that lies behind the importance of this research is to study the indirect effect of installing PV panels on rooftops, as this effect contributes to the total energy consumption of the buildings regardless of their type.

7. Limitations and Future Works

This project's field of study can be developed to encompass various temperature zones, different kinds of roofs, and the electrical incorporation of a PV system to calculate total energy use. It may therefore be beneficial to conduct a study that examines various sorts of energy use, as well as other renovation options in the built environment. Moreover, a needed consideration of the heat transfer mechanism must be adapted between PV panels and roof surfaces to avoid an increase in heating loads. Moreover, passive design strategies can be implemented along with the active system, such as the PV system, to reach maximum benefit to reduce energy consumption. Moreover, an economic analysis for the direct and indirect effects of PV is beneficial to study and convince users more easily; using the life cycle economy concept that considers the actual expenses, operation/maintenance costs, financial returns, and cost savings of the involvement, the conventional evaluation criteria for "financial viability" are assessed. The same assessment criteria are considered in the analysis of solar energy technologies. The yearly generation and the economic factors are impacted by the position, size, and direction of the solar system, the technology used, and the availability of energy storage [46] Moreover, maintenance expenses for the system are included with the economic analysis, and they are referred to as operation costs which includes cleaning the solar panels. The occurrence of soil and dust on solar panels can result in failure, hot surfaces, and power loss which, over time, may compromise their lifespan and energy efficiency. Rain is often enough to wipe away dirt, but when there is significant soiling or in places where there is little rain, extra washing of the roof/façade components is required. Comparing the expenses of energy before and after the renovation (adding the PV system) and transforming this value into money while considering a scheme of an annual rise in the cost of energy procurement can be used to evaluate the economic gains [45]. While, a special consideration should be given to the construction materials that suit each climate zone, the architectural design of the internal spaces also differs from one climate zone to another. There are some restrictions in this research. The load of electrical equipment was left as the standard equipment in the simulation tools without editing them, and also the weather files of the specified area were not accurate as the simulation tools have weather files for a nearby location. It is important to consider how the surrounding environment (such as smog, snow, dark spots, high operating temperatures and installation system effects, incompatibility effects in solar modules and PV arrays when solar cells or modules do not have identical properties, etc.) can decrease the efficiency of energy creation. Another factor to consider is the implementation of the system itself (e.g., slope, temperature increase, decreased air-cooling effect, and natural decline in performance with time) [46]. PV could be used to reduce the construction by using PV panels as a construction material for the roof and walls [47], to calculate the accurate energy required for the building, prior construction, and an accurate building simulation [48] with defined input parameters such as the sky temperature [49] and wind effect [50].

Finally, one of the PV integration criteria elements that needs to be studied more is the energy incorporation criteria, which requires energy efficiency, cost reduction mechanism, and PV system life cycle analysis [51].

Author Contributions: Methodology, A.A. and A.Z.; Software, A.J.; Formal analysis, A.A., R.A. (Renad Albadaineh), R.A. (Ramez Abdallah) and F.M.-A.; Investigation, A.A., A.J. and F.M.-A.; Resources, R.A. (Renad Albadaineh); Data curation, A.A. and F.M.-A.; Writing—original draft, A.A., R.A. (Renad Albadaineh) and R.A. (Ramez Abdallah); Writing—review & editing, A.A, A.Z. and F.M.-A. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Spanish Ministry of Science, Innovation, and Universities under the program "Proyectos de I + D de Generacion de Conocimiento" of the national program for the generation of scientific and technological knowledge and strengthening of the R + D+I system with grant number PGC2018-098813-B-C33 and from UAL-FEDER 2020, Ref. UAL2020-TIC-A2080.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data available on request due to restrictions of privacy or ethics.

Acknowledgments: The authors would like to acknowledge: German Jordanian University, An-Najah National University and University of Almeria for facilitating this research.

Conflicts of Interest: The authors declare no conflict of interest.

Nomenclature

Metric	Imperical
Meter—M	Foot—F
$Kg{\cdot}m^2/s^2$	Joule—J
Kelvin—K	Celsius—C
$Kg{\cdot}m/s^2$	Newton—N
$Kg{\cdot}m^2/s^3$	Watt—W

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