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Evaluating the performance on an air-conditioning system operated by PV panels based on PVsyst software

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Abstract

The main objective of this research is to evaluate a solar panel air conditioning system by using PVsyst simulation software. The software makes analysis, takes into consideration the system details, site parameters, and allows for performance evaluation in May 2023. In order to obtain optimal orientation toward the sun, solar panels were installed on the roof, and a path structure was proposed. This study involves designing and testing of a three-panel solar panel air-conditioning system with 144 Bifacial HJT Mono Half Cell type at 440 W capacity that took place in May 2023. The power produced by these panels as found using PVsyst software. Using this software, we can also experiment with different variables such as changing panel height from .5m to 1.5m or even 2m, and floor reflectance from .4 m to .6 m; .8 m; .95 m respectively. Additionally, we explored out how two axis tracking systems performs compared to a one axis tracking system in terms of energy production levels as well as solar panel efficiencies. The results were analyzed for changes in energy yield and PV conversion efficiency. In order to improve solar cooling technology, this summary presents findings and analyses that provide a basis for policies and actions. It was proved that increasing the height of the panels leads to an increase in energy produced at a height of 2 m. The results indicate that an increase in reflection coefficient resulted into an increase in energy of 0.95. The outcomes revealed that tracking system use results into production of more energy by between 20% and 40% as compared to fixed systems with no sun tracking mechanism. Furthermore, when changing a tracking system from one axis to two axes, there is an increment in power output by about ten percent.

Introduction

Renewable energy, also known as alternative, sustainable, or non-conventional energy, is the energy obtained from natural renewable sources such as wind, solar, hydroelectric, geothermal, bioenergy, and ocean energy. The increasing demand for energy and electricity worldwide and the depletion of fossil fuel reserves have made renewable energy increasingly popular. Renewable energy can serve as a suitable and environmentally friendly source of energy, particularly in remote and rural areas where electricity access is still limited [1]. Installation of transmission lines is not economically feasible. In addition, renewable energy sources are clean and environmentally friendly. However, it has several limitations and challenges. The use of renewable energy is still somewhat limited owing to some obstacles. The first obstacle is its dependence on climate due to variations from one region to another. The energy available at a given location is not fixed at a fixed volume. Sometimes, the energy is zero, for example, the sun's energy at night or on cloudy days [2]. However, this problem has been overcome to some extent with hybrid systems and energy storage systems used as backup arrangements. The second obstacle is the high generation cost. However, for geothermal energy, generating energy from all renewable energy sources, even at a good efficiency level, is expensive compared with current energy methods. The third obstacle is the advancement in technology and marketing [3].

Solar panels are a technology that changes sunlight into electricity by means of solar cells. Photovoltaic panels have traditionally been used as a source of electricity generation for homes and businesses. Nevertheless, there has recently been exploration on using photovoltaic panels to power air conditioning [4]. The increasing cooling needs of societies can be met in an environmentally friendly manner through the use of photovoltaic panels to run air conditioners. The sun's energy is converted into electricity thereby fuelling the air conditioners as opposed to relying on conventional sources like fossil fuels when employing photovoltaic panels for running air conditioners. Installing solar panels on the roof or in any open areas with good sunlight is how one uses photovoltaic panels for powering air conditioners [5]. Solar panels are connected to an air-conditioning system, which provides the required energy for its operation. In addition, sun-tracking systems may be installed to ensure that they always point towards the sun in order to absorb maximum solar energy possible. An air conditioner powered by photovoltaic (PV) panels offers numerous advantages. First, it reduces reliance on the public electrical grid, thereby decreasing the energy consumption required to operate air-conditioners. Consequently, this leads to a reduction in electricity bills [6, 7].

It was found by Chen et al. (2017) [8] that when solar cells are used to power air conditioning systems in commercial buildings, there is up to 30% less of an energy consumption as well as a significant enhancement in energy efficiency. This research suggests that the best way to maximize the benefits of such a system is through selecting highly efficient PV panels and improving energy management. Li et al. (2018) [9] observed that dynamic control technologies and continuous optimization of the settings for PV panel based air conditioning systems can lead to a 25% increase in energy efficiency while minimizing reliance on external electrical grid. Furthermore, this paper recommends use of the smart control technologies for attaining better balance between user comfort and energy consumption. On their part, Zhang et al (2019) [10] had found out that in cases where grid electricity is missing, utilization of standalone PV systems could be a sustainable and cost effective alternative for running air conditioners applications towards zero emission goal. The study advises on how the system should change its features; select panels using photovoltaic technology; and operate it intelligently among other things, so as to provide with an opportunity for achieving its maximum performance and sustainability at any given time. Based on their findings, Zhao et al. (2019) [11] showed that optimal sizing, configuration and control of a photovoltaic panel-based air conditioning system, can improve energy efficiency while reducing costs. Therefore, this study suggests that enhancing design, selection of components with high efficiencies as well as intelligent regulation, are necessary if it should attain optimum performance and economics too (Zhao et al., 2019). Similarly, Song et al.'s study (2017) assessed how well an air-conditioning system based on solar cooling supplemented with solar heating were performing. Using PV/T panels instead would yield both improved thermal performance and reduce costs associated with cooling power requirements. Wu et al. (2020) [13] assessed the energy consumption and thermal comfort of the system under a variety of operating conditions. A study carried out by Zhao et al. (2021) [14] on energy and entropy analysis of heat absorption-based solar air conditioning system. Energy and entropy approach was used in assessing the effectiveness as well as efficiency of the system using an experimental analysis. The purpose of this research, to be done by Zhu et al. (2022)[15], is to maximize system efficiency and minimize dependence on grid electricity. Running at different working conditions, He et al. revealed that cooling capacity and energy efficiency were significant signs for AC systems [16]. To reduce energy intake, these devices would lower carbon emissions, enhance ecological viability, as well as increase user satisfaction (Kapsalis & Founti 2019) [17]. Sun light driven cooling technology has made advancements with commercialization potential in diverse applications according to Wang and Dai (2017) [18]. The findings demonstrated that component efficiency improvement' s together with system control strategies could help raise the performance or solar air conditioning systems resulting into additional energy savings (Chaichan & Kazem 2018) [19]. It has been evidenced by Mohanraj et al. (2010) [20] that these systems contribute significantly towards meeting cooling demand in sun-rich areas. Greenhouse gas emissions are also minimized by reducing dependency on non-renewable sources of electricity like fossil fuels for cooling purposes. Meanwhile, it should be noted that solar air conditioning can serve as a good alternative for conventional air conditioners in many locations where electricity is expensive or insufficient for running traditional equipment (Hasan & Mujahid 2020) [21].

The focus of this research is a simulated software linked to an energy-efficient solar-powered air conditioner that can enhance the efficiency of ordinary air conditioners. Such research may come up with a control methodology for an air conditioning system to operate under nearly ideal circumstances. It is suggested by this study that experiments should be run in Iraqi Kurdistan's climatic conditions.

Solar cooling technology

Solar air conditioning is a promising and attractive alternative to conventional air conditioning, owing to its environmental advantages and energy efficiency. Solar cooling is a technology that converts solar energy into useful cooling or air conditioning in buildings. Solar cooling applications have gained significant global popularity, particularly in countries such as the United States, Europe, Japan, Australia, and China [22]. Reports indicate that Thousands of solar cooling systems have been successfully installed worldwide [23]. According to Henning (2007, p. 1735) [24], solar air-conditioning technology can be divided into two main groups: solar thermal cooling and solar electric cooling. Solar thermal cooling uses solar thermal collectors to provide heat to drive the cooling process, and is usually combined with absorption or convective chillers. Solar electric cooling uses solar cells to generate electricity to drive traditional vapor-compression chillers powered by electric motors. An illustration of the classification of solar cooling technology is given below [25, 26].

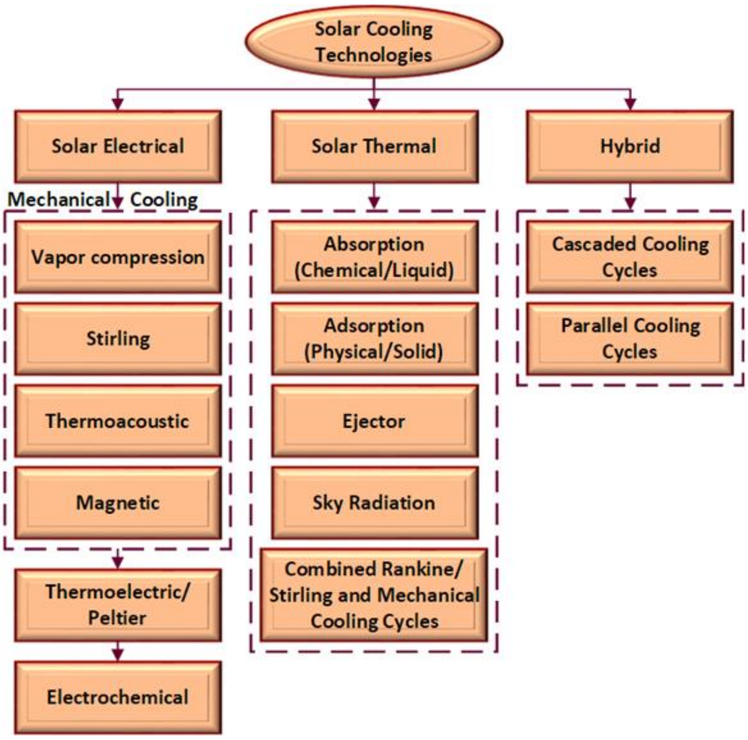


Fig. 1. ***Classification of solar cooling technology*.**

Solar Radiation in the Kurdistan Region

The Kurdistan region experiences an annual average total sunshine duration of 2979.5 hours (equivalent to 8.16 hours per day) and an average annual solar radiation of 1803 kWh/m2/year (equivalent to 4.94 kWh/m2 per day). The radiation values were obtained using simulation software (PVsyst). As shown in **Figure 2**, the values are typical for the region, with the radiation reaching 1000 W/m2. However, some clouds may reduce the irradiance to approximately 500 W/m2 before it increases rises again. To verify these facts, the radiation estimates were revised in comparison with to the information provided by reliable sources [27, 28].

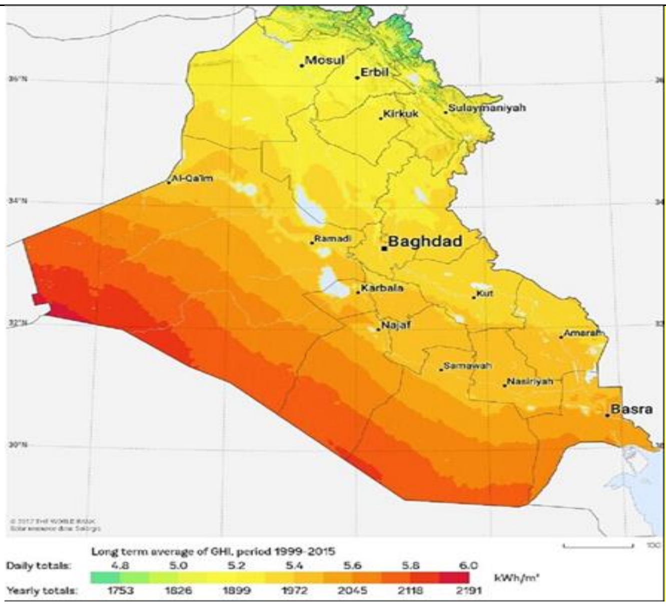


Fig. 2. ***Global horizontal irradiation (GHI) Solar radiation Iraq [29]*.**

A case study in the Kurdistan region

Kurdistan is a region located between latitudes 34° and 39° and longitudes 37° and 46° [30]. The importance of simulation software for renewable energy systems and advances in computational capabilities have led researchers to increasingly adopt photovoltaic system (PVS) software in their investigations, enabling the operator to design the desired model. Many have used previously published experimental results to validate the PVS models they have created.

The increasing preference for validated PVS models is driven by the high costs and limitations associated with experimental airflow analysis. To address these challenges, the current study combines theoretical and computational methods to investigate the use of photovoltaic panels in building adaptation. PVsyst, a solar system analysis and design software, serves as a valuable tool for evaluating the performance of solar air-conditioning systems. This allows engineers and designers to assess the efficiency and effectiveness of solar-powered air-conditioning systems before implementation. The programmer analyzes data such as project location, solar panel orientation, and information related to solar panel performance to determine the amount of solar energy that can be generated and used to operate the air conditioning system. Analyzing the results of PVsyst provides a comprehensive understanding of the performance of a solar air conditioning system. The analysis may include the annual and monthly air conditioning consumption and solar energy production rates. The data input for the programmer is presented in **Table 1**.

Table 1. The data input to the programmer.

Property	Value	Description
Location	House	Type of location where the system is installed
System type	Grid-connected	Type of system, either grid-connected or off-grid
Area of each shed	6.60 m²	Area of each group of solar panels
Width of each shed	3.00 m	Width of each group of solar panels
Ground cover ratio (GCR)	45.5%	Percentage of land area covered by solar panels
Top non-active gap	0.02 m	Distance between the top of the solar panels and the roof
Limit profile angle	15.5°	Limit profile angle, the angle at which sunlight starts to block part of the solar panels
Bifacial factor	80%	Percentage of energy produced from the back side of the solar panels
Height above ground	2.00 m	Height of the solar panels above the ground
Model	Mono 440 Wp Twin 144 half-cells bifacial	Model of the solar panels
Nominal power (STC)	440 Wp	Nominal power of the panel in standard test conditions
Number of modules	3	Number of solar panels in each group
Nominal power of modules (STC)	1320 Wp	Nominal power of the group in standard test conditions
Module configuration	1 string × 3 in series	Configuration of the solar panels in each group
DC:AC power ratio	1.10	Ratio of power produced by the panel to power delivered to the grid

Pmpp	1199 Wp	Maximum panel power at the point of maximum power
Total solar power (STC)	1.32 kWp	Total nominal solar power of the group
Module area	6.7 m²	Area of each solar panel

Proposed model of the cooling system

The experiment was intended to operate a 1.8 KW (3.5 COP) air conditioner with an existing off-grid solar system. An off-grid solar device for air conditioners can indicate that the air conditioners will be completely independent of the grid and can be operated using the energy produced from photovoltaic panel. The proposed system consists of an air conditioner that operates with three solar panels to meet the required power, as shown in **Figure 3**.

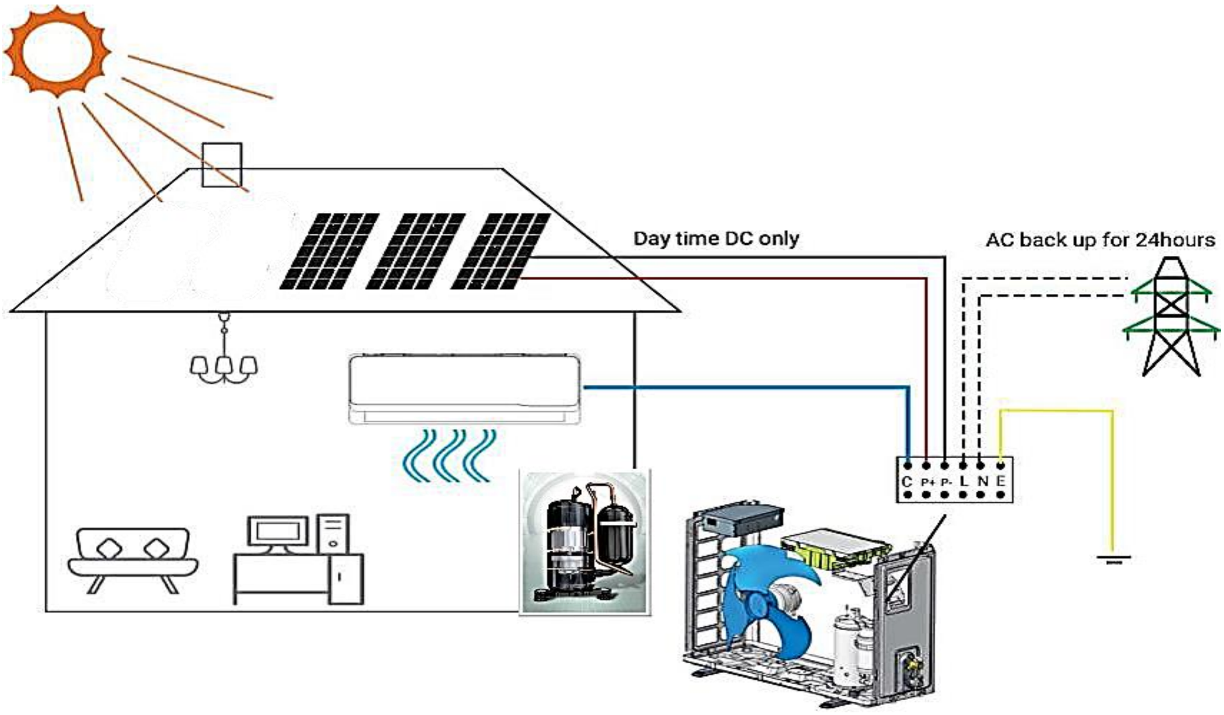


Fig 3. ***The components of the proposed system.***

Experiment analysis

In this study, an air-conditioning system operated by solar panels was designed and tested with three panels of the Type 144 cell Bifacial HJT Mono Half Cell PV Module Series, with a capacity of 440 watts. The solar panels were placed on the roof so that they were automatically directed towards the sun using a tracker system. This helps increase the efficiency of solar energy collection **Figure 4. Figure 5** shows the energy consumption of the air conditioner over the past year, the amount of solar energy used, and the amount of energy from the grid. The value (599 Watt) shows the amount of solar energy used during the past year. The 2,518,168 Watt-hours is the total energy consumption of the air conditioner during the past year. Energy consumption was higher during the summer (shown by the orange line being higher in the warmer months). The energy consumption was lower during winter (shown by the lower orange line in the colder months). The system can be improved by increasing the amount of solar energy generated (by installing more solar panels or by using more efficient technologies). Energy consumption can be reduced during summer (by using energy-efficient practices).

Fig 4. ***The photovoltaic system used in the experiment.***

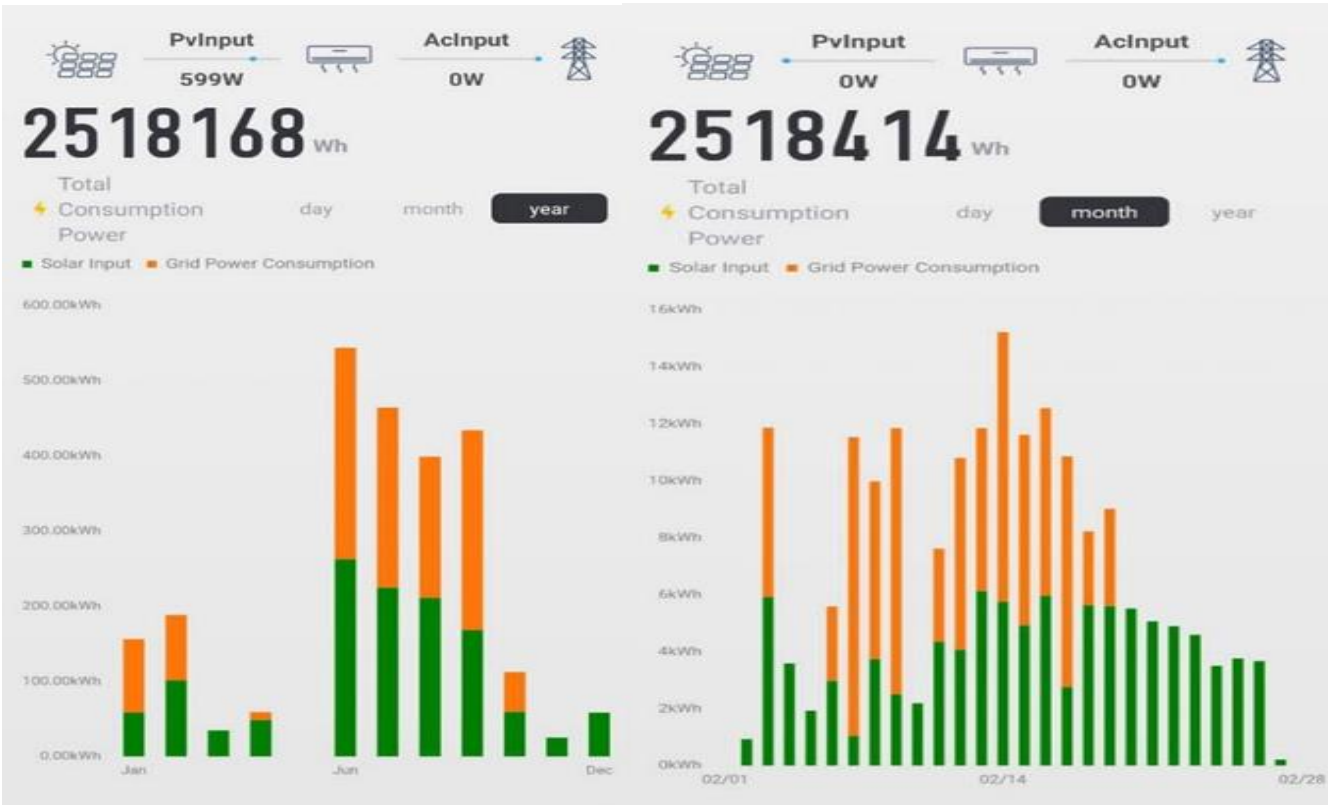


Fig 5. ***Annual and monthly consumption of the air conditioner and the rate of solar energy produced.***

Air conditioner load and solar fraction

Figure 6 shows the energy consumption of the air conditioner in May. The air conditioner was set on a timer from 07:30 to 17:30, with a required temperature of 22 °C. The average running electricity, in all fairness, is consistent at approximately 345 W, and the total electricity call is 3.45 kWh. Additionally, the inverter output AC shows the amount of PV-produced power fed into the air conditioner. Finally, PV coverage indicates the proportion of air conditioner consumption provided with the aid of the PV.

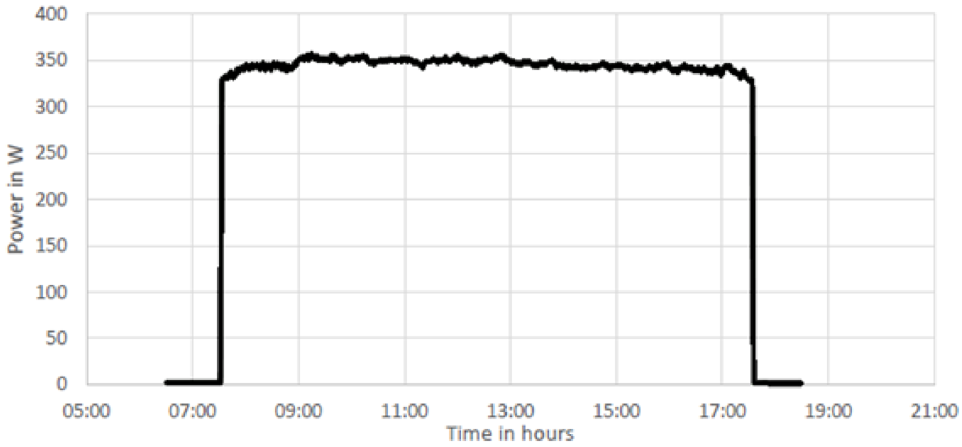


Fig 6. ***Air conditioner load.***

Photovoltaic Power (PV)

Photovoltaic manufacturing may be directly compared to irradiation values. The instances of high photovoltaic production are instances of high irradiation, and the times of low photovoltaic production are instances of low irradiation. The peak irradiance is 1000 W/m2; however, the PV system can provide 480 W/day. The PV output power per month under solar radiation is shown in **Figure 7**.

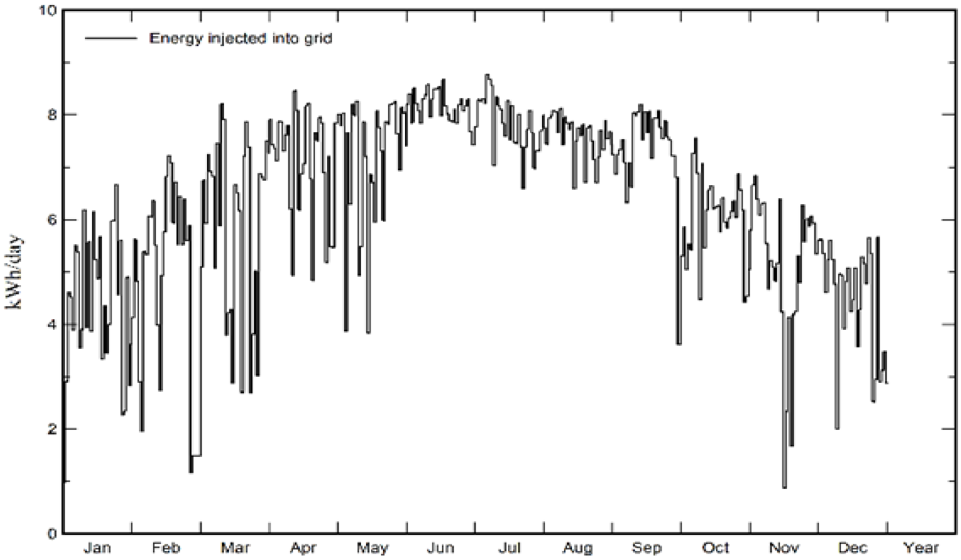


Fig 7. ***The PV output power per month.***

Grid Backup power

Figure 8 shows the backup energy utilization from the grid on a cloudy day in May (a cloudy day to determine the rate of decrease in solar radiation and the amount of energy withdrawn from the electrical grid). From 08:00 to 10:00, there was a decrease in solar radiation due to cloud insurance. During this period of decreased solar strength production, the backup strength from the grid was required. The required power reached 250 W a few times, which means that the highest 100 W of solar panels had been produced. From 11:00 to 15:00, the radiation is again at a high level, and there may be no need to rely on the grid as a backup source. Starting at 15:00, solar started to set, and the grid became the most effective source for operating the air conditioner. In this grid-related system, there are no batteries; therefore, power cannot be saved for the remaining hour of the day. The grid is extensively utilized to operate air conditioners, but it is far too short to be seen in this diagram.

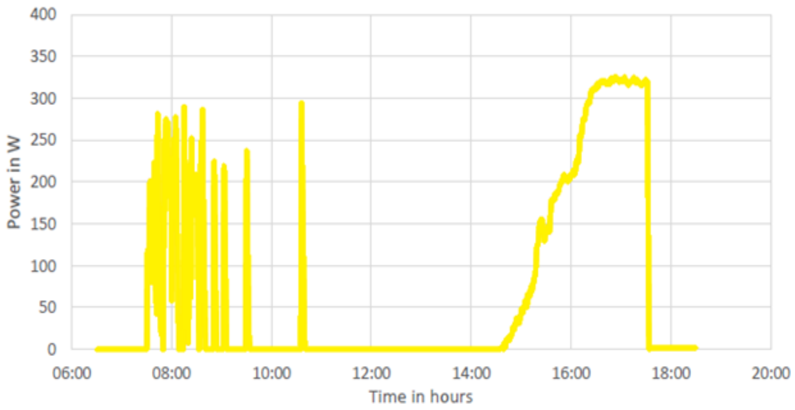


Fig 8. ***The backup energy utilization from the grid on a cloudy day in May.***

Figure 8. Shows the backup energy utilization from the grid on a cloudy day in May. Whereas **Figure 9** shows the air conditioner supply, solar cellular energy, grid-supplied power, radiation intensity and generated power supply to the grid on May 10. It explains how an air conditioner works, the mechanism of solar panels, and solar energy. May 10 was chosen because it is an excellent example of what happens on sunny days. Between 05:30 and 07:30, the sunrise and the depth of radiation increase, and the sun modules begin to produce energy. The air conditioning was not turned on, so all the electricity produced by the solar cells was fed into the grid. At 07:30, the air conditioner was turned on. At this time, the productivity of the solar cells is not yet sufficient to power the entire air conditioner, so a little power from the grid is likewise required as an extra backup. A network guide is also necessary to start an air conditioner. The startup system cannot be seen within the discern, as it happens in much less than 1 second, and the values used are precise. From 08:00 to 10:00, the radiation depth and sun productivity increased. The electricity of the solar cells reached 450 W during this period. The consumption of the air conditioner was 350 W; therefore, 100 watts of excess energy was fed into the grid. At 10:00, there was a sharp drop in sun cellular productivity, although this was not always proven inside the irradiance effects. This lack of electricity is probably due to cloud masking of the sun modules for a short time. This power scarcity no longer affects the operation of the air conditioner because the grid provides backup. Between 10:00 and 14:00, the sun cellular gadget operates as usual, offering energy to the air conditioner and extra power fed again to the grid. From 14:00 to 14:40, the sun began to set.

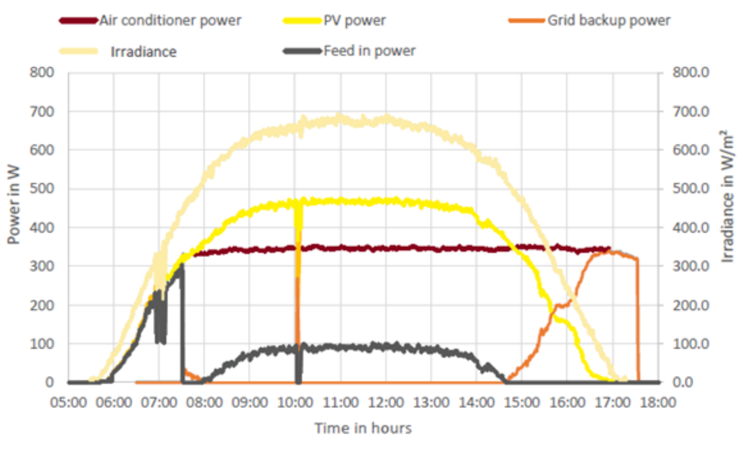


Fig 9. ***Operating conditions of the air conditioner with PV on a sunny day.***

In **Figure 10**. The results show how the device worked in partly cloudy situations on May 25. The weather in the morning on this day can be described as scattered clouds, cloudy for one minute, and sunny for the following. Rather than steady low irradiation in this weather method, the irradiation is usually converted; consequently, the PV electricity usually changes. Here, PV manufacturing goes from extra power to inadequate strength. Without any storage, the air conditioner must use energy from the grid to maintain operation. Without grid backup, the PV strength would not be sufficient to strengthen the air conditioner.

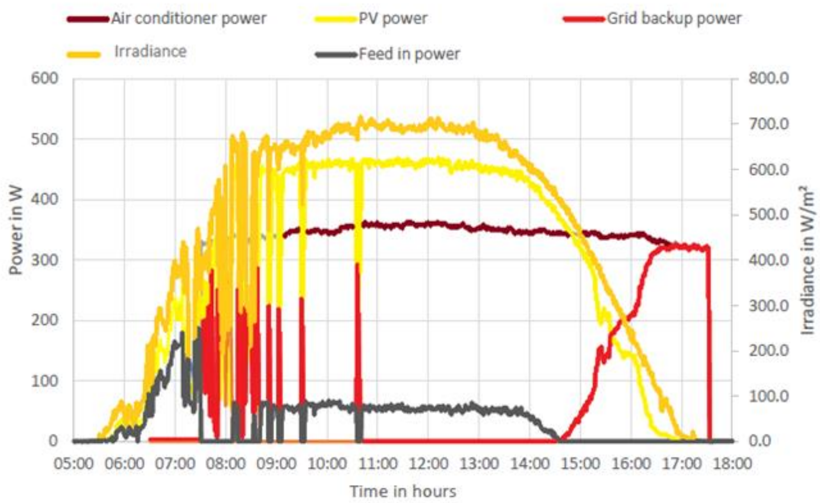


Fig 10. ***Operating conditions of the air conditioner with PV on a cloudy day*.**

Analyzing the results of PVsyst

A photovoltaic system was simulated using PVsyst software. The load used in the simulation was a (COP of 3.50). The homeroom system is very good size for an air conditioner. This provided a 10 kW photovoltaic system for existing air conditioners. Figure 4 shows the main components of a 10 kW grid-connected photovoltaic system. Tests to find the best location for the PV array have already been conducted by previous research. These results can be used to evaluate system efficiency and predict long-term energy consumption and operating costs. As for the effect of variables (height, ground inverter, and tracker system) on the energy productivity of the solar Simulation, results indicate that the system has a total power of 1320 W. The total annual energy production of the system was calculated to be 2264 kWh. This number was calculated based on the solar radiation available in the safe region of Iraq. The term "specific throughput" was used to evaluate the system performance. According to the Simulation report, the system's specific output per year is 1,715 kWh for every kilowatt-hour of solar energy installed in the system. This is an important parameter for evaluating the efficiency of a system. Rated performance (PR) indicates the efficiency of the system in converting solar radiation into electrical energy. According to the Simulation report, the performance factors (PR) of the system were 83.37%, 84.74% and 85.89%, respectively **Table 2**. A high coefficient of performance indicates that the system operates with a good efficiency. The Simulation report displays a chart of losses in the system. Losses are introduced in different parts of the system, such as the solar panels, wires, and transformers. The losses can be due to factors such as the scattering of solar radiation, wire resistance, and power loss during conversion. The results of the air-conditioning system can be displayed and analyzed as follows:

Table 2. Energy produced for one year

Month	GlobHor KWh/m²	T-Amb ℃	GlobInc KWh/m²	GlobEff KWh/m²	EArray KWh	E_Grid KWh	PR ratio
January	80.2	7.34	112.7	109.4	146.8	136.7	0.919
February	92.6	8.9	118	114.9	154.1	143.3	0.921
March	133.1	13.13	154.3	150	196.5	182.7	0.897
April	170.6	17.28	183	178	228.6	213.2	0.882
May	195.9	24.13	197.4	191.9	239.6	222.6	0.855
June	229.9	30.76	225.4	219.9	263.2	244.9	0.823
July	229.9	34.94	228.6	222.8	261.1	243.0	0.805
August	210.6	34.07	222.1	216.7	252.4	235.5	0.803
September	178.2	28.72	204.9	199.9	237.2	221.2	0.818
October	130	22.74	163.6	159.6	199.1	186.2	0.862
November	93.2	14.08	131.1	127.5	165.3	154.1	0.891
December	78.5	9.20	115.9	112.9	149.0	139.1	0.909
Year	1822.6	20.51	2057	2003.6	2493.0	2322.3	0.855

Where GlobHor, Horizontal diffuse irradiation, DiffHor, Global horizontal irradiation, T_Amb, Ambient Temperature, GlobInc, Global incident in column. Plane, GlobEff, Effective Global, Corr for IAM and shading, PR, Performance Ratio.

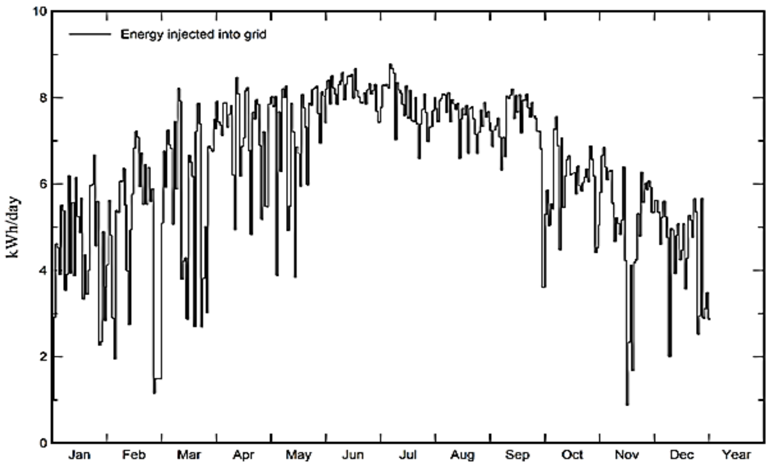
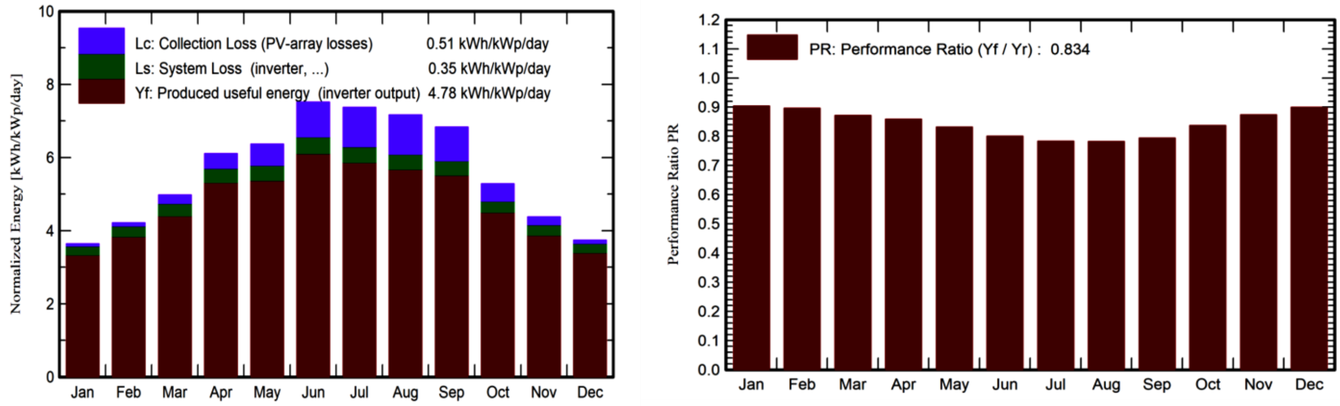


Fig. 11. ***PV output power per month.***

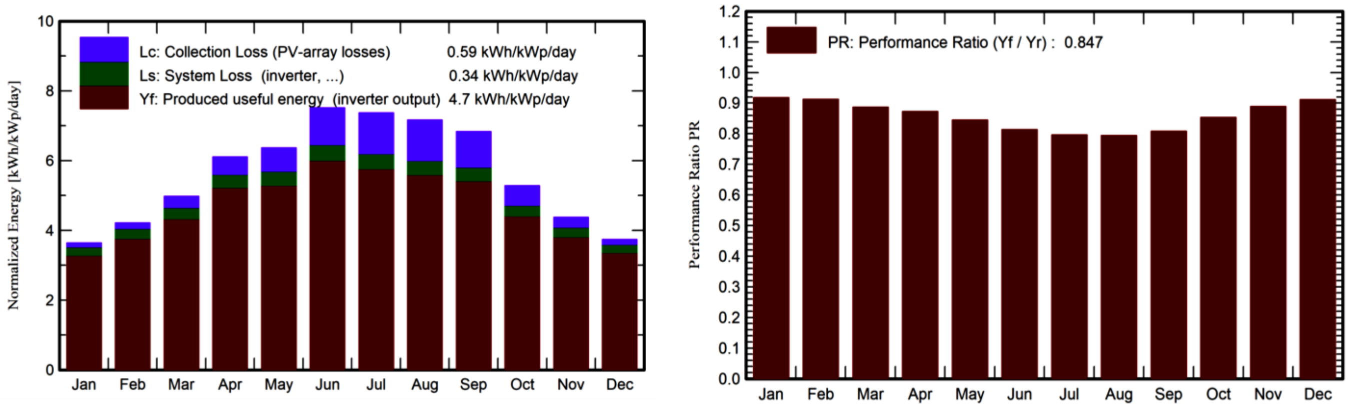
Photovoltaic manufacturing can be directly compared to irradiation values. The instances of high photovoltaic production are instances of high irradiation, and instances of low photovoltaic production are instances of low irradiation. The peak irradiance was 1000 W/m2, and the height irradiance was 700 W/m2, the top PV manufacturing was ready at 480 W for each day **Figure 11** shows the PV output power per month for solar radiation.

Possible effects of panel height

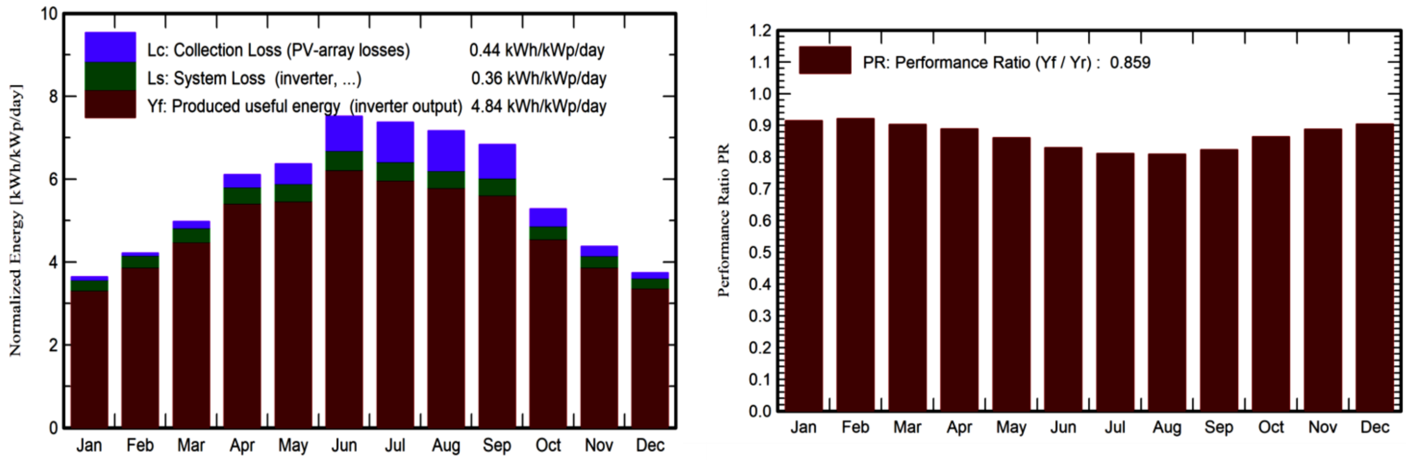
The heights of the solar panels above the ground surface were adjusted to 0.5 m, 1.5 m, and 2m. This modification can affect energy production as it alters the ambient conditions. For instance, increasing the height can enhance the airflow around solar modules, leading to better cooling and increased efficiency. Height may lead to a change in the distribution of solar radiation on Earth's surface. There may be a decrease in radiation as elevation increases, which can negatively affect the productivity of the solar modules. The aforementioned results of a cooling system using solar energy and changing the height of the PV modules from the roof show that with increasing height, the amount of energy produced increases proportionately. Therefore, when the height of the panel is 0.5 m, the system can produce 2264 kWh/y of energy, while the produced capacity increases to 2301 kWh/y when the height is 1.5 meters and reaches 2332 kWh/y at a height of 2 m. As shown in **Figure 12**, slight qualitative changes in the specific energy produced can be observed with increasing altitude. Therefore, the specific energy produced is 1715 kWh/y when the height is 0.5 m, increases to 1793 kWh/y when the height is 1.5 m, and then decreases slightly to 1767 kWh/y when the height is 2 m. Generally, it is observed that increasing the height of PV modules increase the total energy produced and may have a slight impact on the specific energy produced. Increasing the height increases the efficiency of solar energy use and improves the performance of the system.



Normalized productions (per installed kWp & Performance Ratio PR at 0.5 m



Normalized productions (per installed kWp & Performance Ratio PR at 1 m



Normalized productions (per installed kWp & Performance Ratio PR at 2 m

Fig. 12. ***The effect of the panel's height on the performance at a distance of (0.5, 1.5 and 2 m).***

Possible effects of albedo reflector

The floor albedo changed at reflectance rates of 0.4, 0.6, 0.8 and 0.95. Ground-level solar radiation falls on the solar modules. When the reflectance value is high (0.95), the amount of radiation received from the solar modules can be increased, resulting in an increase in the energy yield. However, when the reflectance value is low (0.4), the amount of radiation received by the solar modules is less, and thus the energy productivity decreases. The reported results of changing the reflectance rate show that increasing the reflectance ratio leads to an increase in the total power produced. Therefore, when the reflection rate was 0.4, the system produced 2375 kwh/y of energy, and the energy produced increased to 2479 kwh/y when the reflection rate was 0.6, reached 2582 kwh/y when the reflection rate was 0.8, and reached 2659 kwh/y when the reflection rate was 0.95. As shown in Figure 13, a gradual increase in the specific energy produced can be observed with increasing reflection ratio. For example, the specific energy produced was 1799 kWh/y when the reflection rate was 0.4, increased to 1878 kWh/y when the reflection rate was 0.6, reached 1956 kWh/y when the reflection rate was 0.8, and then reached 2015 kWh/y when the reflection rate was 0.95. In addition, it appears that increasing the reflection ratio improves the efficiency of the system performance. A gradual increase in efficiency can be observed as the reversal rate increases. For example, the performance efficiency was 87.46% when the reflection rate was 0.4, 91.30% when the reflection rate was 0.6, 95.11% when the reflection rate was 0.8, and 97.95% when the reflection rate was 0.95.

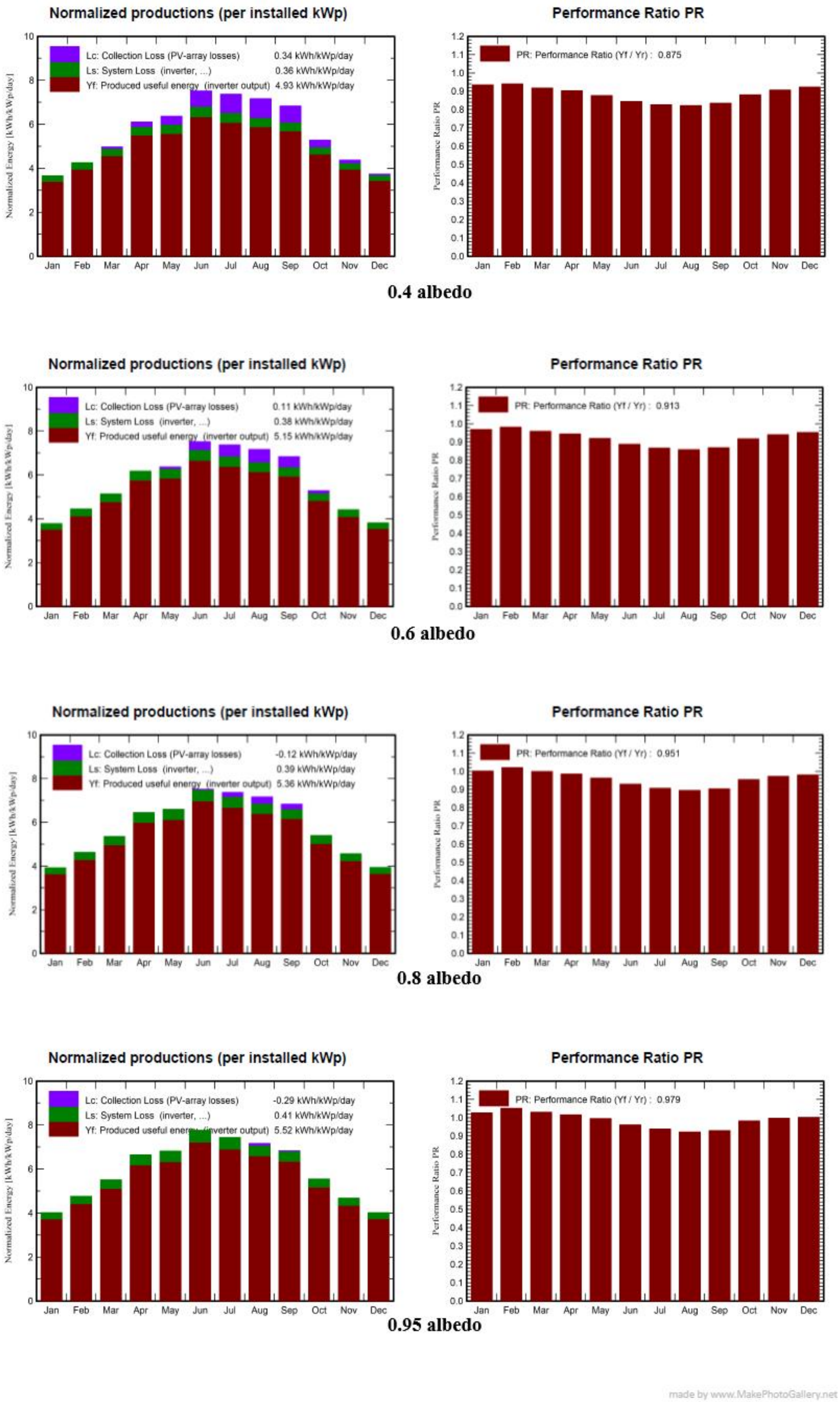


Fig. 13. ***The effect of albedo energy produced.***

Possible effects of the tracker system

A one- and two-axis track system was suggested to allow solar modules to track the movement of the sun throughout the day. This means that the solar modules will benefit from the sun's radiation more and over a longer period. Depending on the orientation of the solar panels, a 20% to 40% increase in energy productivity can be achieved compared with a fixed system that does not track the sun. When the tracker is changed from one axis to another, an increase in the power produced occurs. Therefore, when the tracker was shifted from one axis, 2383 units of energy were produced. When changing the tracker from two axes, 2978 kWh/y of energy was produced, as shown in **Figure 14**. The actual energy is obtained based on the efficiency of the system and the energy produced. The results show that the actual power is less than the power produced if the tracker is changed from one and two axes. Therefore, when changing the tracker from one axis, an actual power of 1805 kWh/y is achieved, and when changing the tracker from two axes, an actual power of 2256 kWh/y is achieved. The performance efficiency can be calculated based on the actual power produced. If the tracker was changed from one axis, the performance efficiency was 80.44%; if the tracker was changed from two axes, the performance efficiency was 80.39%. From these results, it can be concluded that changing the tracker from a single axis leads to a slight increase in the produced and actual power, and the performance efficiency is stable. When changing the tracker two axes, there is a greater increase in the produced power and the actual power, and the performance efficiency is stable.

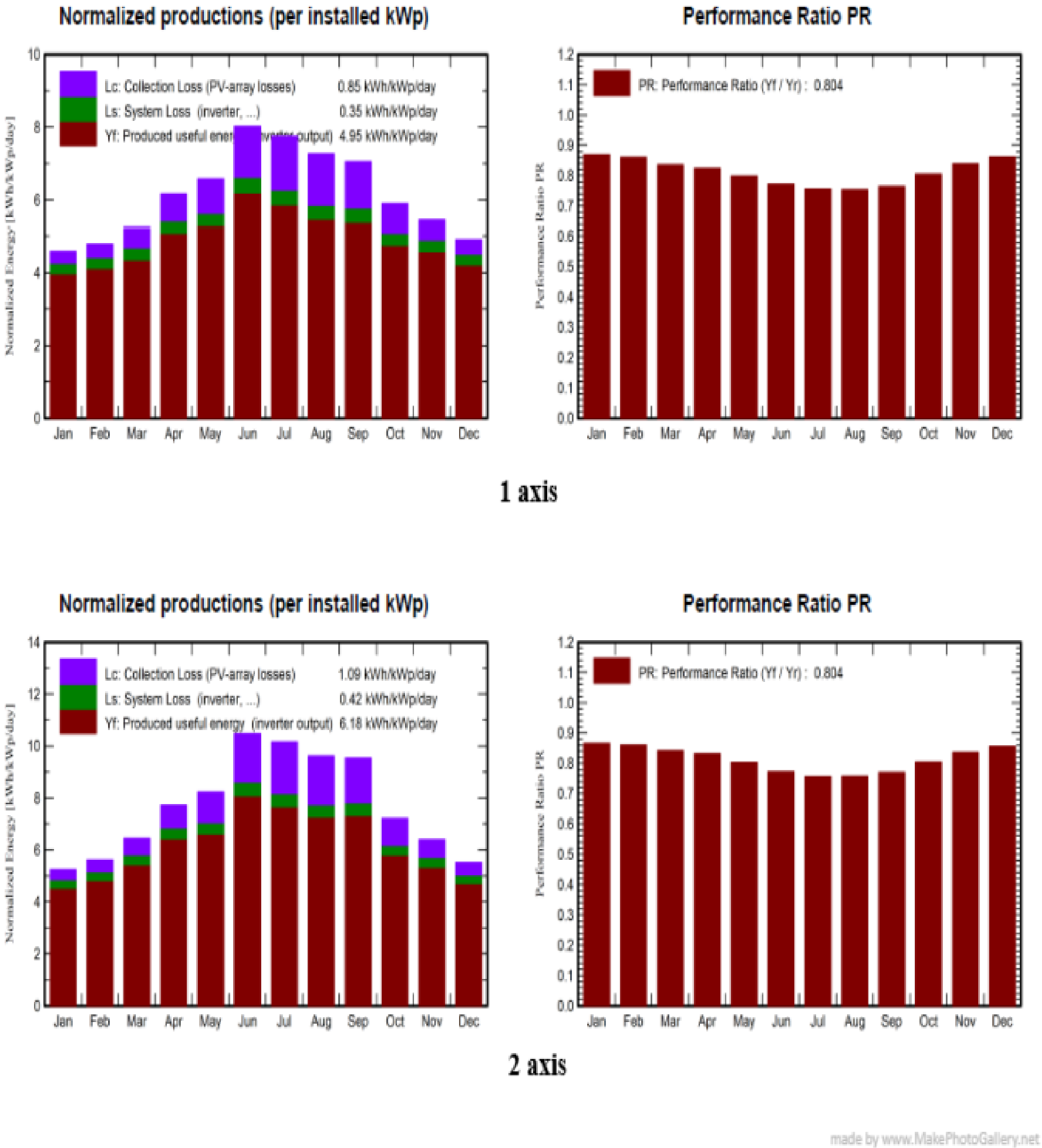
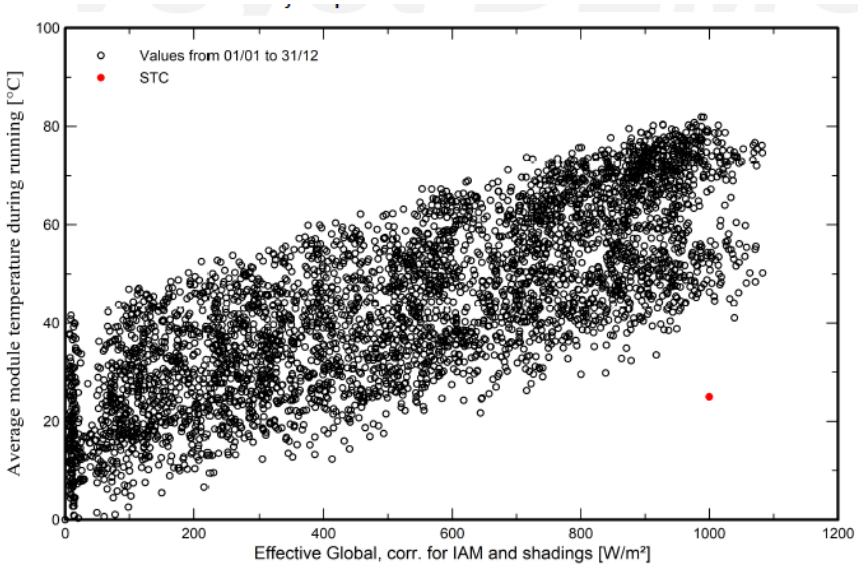
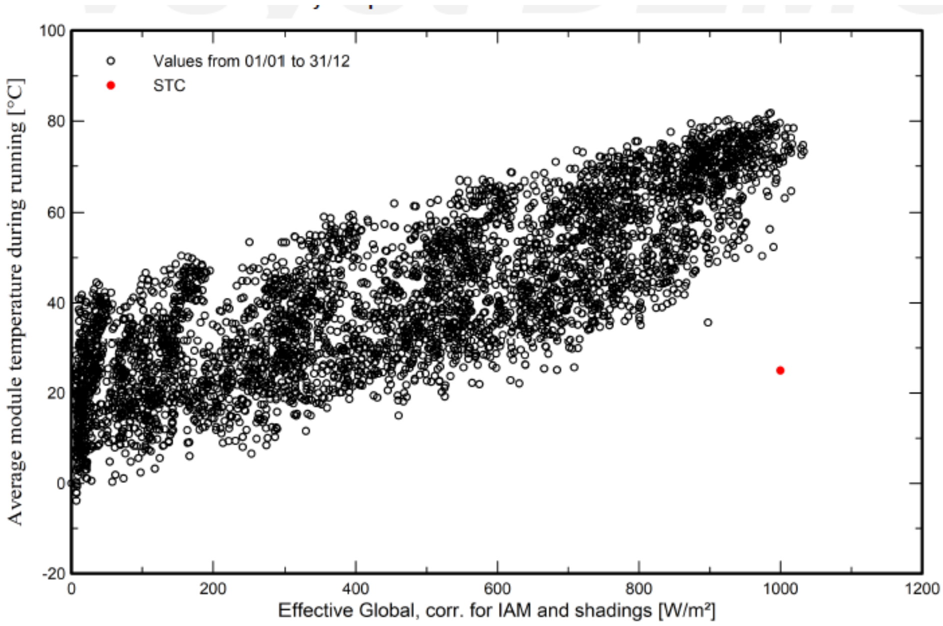


Fig. 14. ***The effect of the tracker on the energy produced.***





Two-axis

Fig. 15. ***The effect of temperature on the solar panels of the tracking system*****.**

Figure 15 shows the solar energy data for the solar system. The data covers the period from January 1 to December 31. The vertical axis shows three measurements: panel temperature in red, effective radiation in blue, and energy produced daily in green. panel temperatures ranged between 20°C and 80°C. highest temperatures at: July (80°C), August (70 °C), June (60 °C), lowest temperatures were: December (20 °C), January (20 °C), and February (30 °C). Daily energy production in July (10 kWh/day), August (9 kWh/day), and June (8 kWh/day), while the lowest production was in December (2 kWh/day), January (2 kWh/day), and February (3 kWh/day). From the results, we conclude that there is a relationship between panel temperature and effective radiation. The data show an inverse relationship between the panel temperature and effective radiation. At high temperatures and radiation, the energy is low.

Economic evaluation

A cost analysis of the proposed grid-connected systems was performed, including the total investment, payback period, and levelized costs. The results for the 10 kW PV systems are presented as air conditioners with a COP of 3.5. Since it is not entirely clear whether feed will be paid into the tariff, this economic evaluation is calculated with and without feed in the tariff. The feed in the tariff is not affected by inflation because it is a fixed rate. PV modules from HUASUN, manufactured in China, are used, and the feed-in tariff is assumed 0.12 USD /kWh. The tariff was converted to 156 IQD per KWh. The project was supposed to be 25 years old. To calculate the economic feasibility of the system, the expected costs and returns over a 25-year period must be determined.

- ***Initial costs***

$$Cost\ of\ 3\ solar\ panels: 3\ x\ 180\$\ =\ 540\$$$
$$The\ cost\ of\ the\ air\ conditioner: 675\$$$
$$Cost\ of\ baseboards: 300\$$$
$$Installation\ cost: 100\$$$
$$Total\ initial\ cost: 540\ +\ 675\ +\ 300\ +\ 100\ =\ 1615\$$$

- ***Annual costs***

System maintenance and operation can be estimated at 2% of the initial total cost.
Therefore, 0.02 x 1615 = 32.3$ per year.

The daily consumption of the system is 300 watts. The expected annual return was calculated as follows:

$$Annual\ electricity\ consumption\ =\ capacity\ x\ number\ of\ hours\ per\ day\ x\ number\ of\ days\ per\ year$$
$$Annual\ electricity\ consumption\ =\ 300\ watts\ x\ 24\ hours\ x\ 365\ days\ =\ 2{,}628{,}000\ Wh.$$

To calculate the annual financial savings, the cost of electricity must be calculated and multiplied by the amount of annual electricity consumed.

$$Annual\ financial\ savings\ =\ annual\ electricity\ consumption\ x\ electricity\ tariff$$
$$Annual\ financial\ savings\ =\ 2{,}628{,}000\ watt-hours\ x\ 0.12\ \$/Wh\ =\ 315360\ \$$$

We now use the previously calculated values to calculate the net return and payback periods for the initial investment cost .sIf the total initial cost of the system is 1,615 $ and the annual financial savings are 315,360 $ (according to previous calculations), the annual net return can be calculated as follows:

$$Annual\ net\ return\ =\ annual\ financial\ savings\ -\ annual\ costs$$
$$Annual\ net\ revenue\ =\ 315{,}360\ \$\ -\ 32.3\ \$\ (annual\ maintenance\ and\ operating\ costs).$$

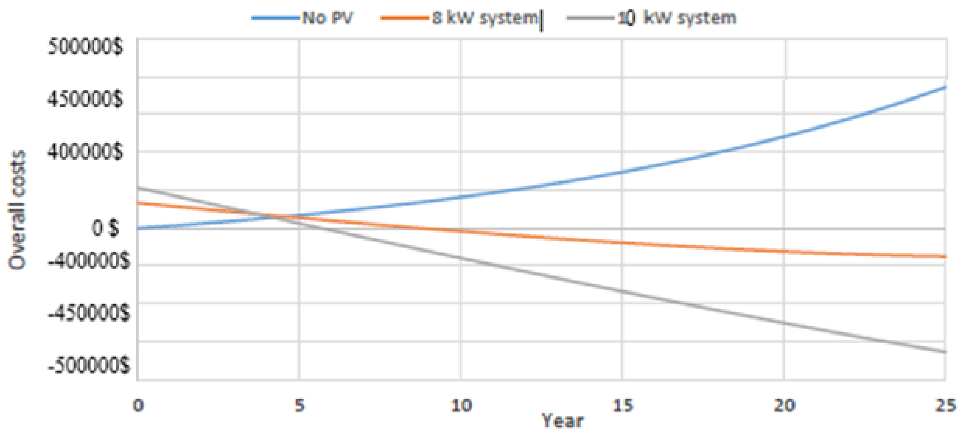


Fig. 16. ***Overall costs of the project.***

Figure 16 shows the initial investment costs over the life of the project with feed-in tariffs for consumption without photovoltaic panels at 8 KW system and 10 KW systems. The payback periods for the PV systems can also be read from the numbers. The lines from the PV systems intersect the line without the PV system.

Table 3. Nomenclature

Nomenclature	
PVsyst	simulation software
PV	photovoltaic
GHI	Global horizontal irradiation
COP	Coefficient of performance
PR	Rated performance
W	watt
°C	Temperature
IQD	Iraqi Dinar
USD $	American dollar
kW	Kilowatts
m2	area
GlobHor	Horizontal diffuse irradiation
T_Amb	Ambient Temperature
PR	Performance Ratio

Discussion

As mentioned previously, one of the main motivations for conducting this study was to examine the interaction between PV energy production and air conditioning use. When comparing the PV energy production throughout the day with working hours (07:30–17:30), the values were found to be very high. An average of 3.5 kWh is produced throughout the day, and an average of 3.3 kWh is produced during working hours. Only 0.2 kWh was produced outside of working hours, meaning that almost all of the electricity produced was available during working hours. This is useful in countries without high feed-in tariffs, where only a small amount of feed into the grid is needed. The backup network in this system has two primary functions. The first function is to supply power to the air conditioner when the PV power output is low. The backup network uses an average of 20% of the air conditioner's consumption, and most of it is used in the last two hours of the day when the radiation is low. To reduce the dependence on the grid, the PV panels need to be large, but from 15:00 onwards, the radiation on the panels is less than 300 W/m and decreases rapidly. If the air conditioner is operated during this time using PV energy, it will significantly increase the size of the system unless batteries are used to store excess energy during the day. However, as previously mentioned, this is an expensive solution. A second use for off-grid backup is to run the air conditioner during startup; this eliminates the need to upsize the inverter, as would be required in an off-grid system. By using grid backup, one does not rely on the energy stored in the batteries while starting the air conditioner, which reduces the need for large batteries in the PV system. In general, it can be said that using PV energy to power air conditioners is possible and effective in certain situations. However, several factors must be considered, such as the size of the PV system, amount of energy produced, energy consumption requirements of the air conditioners, cost of equipment and installation, cost of maintenance, and cost of battery storage. With these results, it is possible to judge the possibility of designing solar systems with the air conditioner to achieve the best efficiency for operating the air conditioner. The three factors that were affected were as follows:

1. Effect of the height of the panels: It was proven in the study that increasing the height of the panels leads to an increase in the amount of energy produced. This can be attributed to the improved airflow around the solar modules, which helps cool the modules and increase their efficiency. Height may also cause a change in the distribution of solar radiation on Earth's surface. There may be a decrease in radiation with increasing altitude, which negatively affects the productivity of the solar modules.

2. Effect of the reflection coefficient (albedo): The reflection coefficient of Earth was changed, and its effect on energy production was tested. The results show that increasing the reflection coefficient led to an increase in the energy produced. A high reflectance value can increase the amount of radiation received by solar modules, resulting in an increase in productivity. On the contrary, when the reflectance value is low, the amount of radiation received by the solar modules will be lower, and thus the power production will be less.

3. Effect of tracking system: A two-axis tracking system and a single-axis tracking system were used in the study. The tracking system allows the solar modules to track the movement of the sun throughout the day, which means that the solar modules will benefit from the sun's radiation better and over a longer period. The results showed that using a tracking system leads to an increase in the energy produced by between 20% and 40% compared with a fixed system that does not track the movement of the sun. In addition, when changing the tracking system from a single axis to two axes, the power output increased by up to approximately 10%.

Conclusion

Based on research conducted on solar cooling technology in the Kurdistan Region, it has been demonstrated that this sustainable and efficient air-conditioning solution offers tangible environmental and economic benefits. Experiments and simulations carried out on a solar air conditioning system using photovoltaic panels (PVS) revealed important findings. The height of the panels above the ground was varied between 0.5, 1.5, and 2 m. The results showed that the best energy production was achieved at a height of 2 m. Additionally, the average reflection coefficient of the floor was tested at values of 0.4, 0.6, and 0.9, and the simulation indicated that the highest efficiency was achieved at a reflection coefficient of 0.9. Moreover, the study investigated the impact of the tracker mechanism on system performance by comparing single- and dual-axis trackers. The results indicate that the dual-axis tracker yields better outcomes. These findings provide valuable insights into the design of solar energy systems integrated with air conditioning units, enabling the achievement of optimal efficiency in operating air conditioners. The research also highlighted the potential of solar panels to power air-conditioning systems in commercial buildings, with the potential to reduce electricity consumption by up to 30% and significantly improve energy efficiency. This presents an opportunity to achieve substantial energy savings and reduce the carbon footprint of Iraq. In summary, this research underscores the potential of solar cooling technology as a sustainable and effective solution for air conditioning in the Kurdistan Region. By addressing the identified challenges and implementing them, the recommended measures, significant energy savings, reduced carbon emissions, and enhanced system performance can be achieved.

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