Water Harvesting Research Vol. 6, No. 1, Spring & Summer 2023, Original Paper p. 55-69

University of Birjand

10.22077/JWHR.2023.6846.1111

Simultaneous Supply of Energy and Water by Rainwater Harvest from the Roof of the Greenhouse Structure with a Solar Panel

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Received: 03 October 2023/ **Revised**: 19 October 2023/ **Accepted**: 29 October 2023

Abstract

Greenhouse production in areas with suitable potential has developed significantly due to the economic and technical advantages of this method. Khabr region in the south of Kerman province has very good potential for agriculture and renewable solar energy production. In this research, using the design of the greenhouse structure with roofs of solar panels and a rainwater harvest system, the amount of energy produced and collected water has been simulated and estimated. After examining the 20-year rainfall data of the Khabr region, monitoring the amount of radiation in the region, and also determining the suitable location for installing the greenhouse and solar panels, the digital height of the region were obtained and its topology and slope were estimated using ArcGIS software. After determining the appropriate location and designing the greenhouse structure, using PVSol software version 2021, in three different scenarios of solar panel installation, simulation has been done and energy-related parameters have been estimated. The simulation results showed that with this method and placing the flat panel roof with an angle of 28 degrees, on the land of about 2 hectares, more than 60,000 cubic meters of rainwater was collected annually, and the electric energy amounted to 17227057 kilowatts per year and the electric power produced from these installed solar panels is estimated at around 9 MW. In addition to helping the environment and increasing the productivity of the production process, this project also leads to the optimal use of rainwater.

Keywords: Agricultural Greenhouses, Rainwater harvest, Renewable Energy, PVSol, Solar Panel, Simulation.

1. Introduction

Providing sustainable water and energy without harming the environment is an inevitable necessity. This issue doubles especially in areas that have environmental and protected value and have high social, economic, and agricultural potential. The successive droughts of the last few years in the southern regions of Iran have been a serious challenge for humans and the surrounding environment. Climate changes in the past few years have led to water shortages and changes in agricultural conditions. Maximum use of the existing potentials in these areas for a sustainable supply of energy and water, without causing any damage to the ecology of the areas, is a necessity that should be given special attention. In the meantime, the issue of productivity, and the least change of use of areas with cultivation potential or under environmental protection should be taken into consideration. One of the protected areas in the south of Iran in Kerman province is Khabr village, which is one of the protected areas and has a very good potential for agriculture and tourism (Saleh et al., 2020). The climate of Khabr village is mild and has cool summers and relatively cold winters. Most of the population of the Khabr region has migrated to the cities of Bandar Abbas, Kerman, and Sirjan due to the lack of sufficient sources of income, and for this reason, the population of this village is changing. In the summer season, the population is high, and in the fall and winter, the population decreases. In 2006, Khabr district was considered a target village for tourism by the Organization of Cultural Heritage, Tourism and Handicrafts, and it has attracted the attention of many tourists so that the non-native population of Khabr area varies between 20,000 and 30,000 people in the summer season and holidays (Pourmirzaie, 2021). In the cool seasons of the year, the Khabr region faces a huge entrance of tourists, and this issue leads to a serious challenge in providing water and energy for this sudden increase in population. During these times, the areas of this region will suffer from a lack of electricity and successive blackouts, which will lead to the complaints of the residents. Since this area is one of the protected areas, it is not possible to provide water and energy to it by any means, because it may lead to the pollution of the region's ecosystem and water pollution (Varesi et al., 2015).

Therefore, one of the best ways is to use renewable resources and multiple uses of them to provide water and energy in this region. The presence of the population outside the ecological capacity of the region and the lack of welfare infrastructure and energy supply have caused serious environmental damage in this village. To provide energy to this region and the importance of tourism and the environment of the region, the way to provide this energy is very important. According to the monitoring of the area, solar energy and the use of solar panels in this area can produce healthy renewable energy. One of these methods is the use of solar panels on the roofs of structures and the creation of a piping system for rainwater harvest. This method has increased significantly especially in areas that have suitable agricultural potential and suitable radiation and have a rainy climate. This method increases the productivity of the process, reduces costs, and simultaneously provides water and energy in these areas. Considering that the area has suitable potential for cultivation, especially greenhouses and medicinal plants, installing and creating the greenhouse in this vast area, along with the installation of solar panels as a roof on them, and also according to the appropriate amount of rainfall in the area, the creation of gutters next to the solar panels and suitable tanks and piping to collect rainwater.

It will lead to multiple uses of this system and significantly increase productivity. With this method, in addition to reducing project costs, and energy production, the ground under this panel will be used for cultivation and its roof will be used for rainwater harvest. These are the goals that are mentioned and emphasized in the UN sustainable development programs. There are always limitations in research based on modeling and simulation. The most important limitation of this research is the lack of climatic field data. Since this research was conducted in one of the rural areas in the south of Kerman province, among the climatic data, only the rain and temperature data from the station installed in Khabr village could be monitored, and other data such as humidity, wind speed, and the amount of dust present.

Another existing limitation is the lack of economic feasibility in this project. Due to the variable rate of equipment required and required in the construction of greenhouses and solar electrical equipment, it is not possible to monitor the economy and reach reliable results in this sector. To validate the output results of the simulation, the existence of similar research can be a good help. Due to the lack of similar research in terms of application, climatic and technical conditions, etc., it is not possible to compare the data output with the data of the research conducted in the Khabr region or similar regions in Iran. And it is only possible to make a relative comparison with similar research in other countries.

Examining the research and similar researches will greatly help in reducing the research costs and using these experiences will reduce the time and also improve the past methods.

The use and application of solar panels as a structure roof have been increasing in these years and a lot of research has been done on the effects of this method. The use of solar photovoltaics in agricultural greenhouses could result in co-production of food products and electricity. The technical and economic feasibility of using semi-transparent solar panels on the rooftop of greenhouses in Crete, Greece has been investigated. It is concluded that the use of semi-transparent solar panels on the rooftops of greenhouses in Crete, Greece would result in economic and environmental benefits for the farmer (Vourdoubas, 2020).

An intense research effort in the field of energy production from renewable sources has increasingly led to the development of greenhouses which are partially covered by photovoltaic elements. The purpose of this study is to present the potentiality of an innovative prototype photovoltaic greenhouse with variable shading to optimize energy production by photovoltaic panels and agricultural production. The results show how the shading variation enabled regulation of the internal radiation, choosing the minimum value of necessary radiation, because the internal microclimatic parameters must be compatible with the needs of the plant species grown in the greenhouses (Moretti and Marucci, 2019).

The effect of semi-transparent building integrated photovoltaics (BIPV) mounted on top of a greenhouse, on the growth of tomatoes and microclimate conditions as well as to estimate the generated energy and the payback period of this system, have been estimated. Three modules were settled at 20% of the greenhouse roof area at a tilt angle of 30 facing south at a distance of 0.08m between the plastic cover and the BIPV. Results revealed that the annual generated electric energy of the BIPV was 637 kWh. Furthermore, there were no significant differences ($P < 0.05$) in the growth of tomatoes between the shaded greenhouse by the BIPV and the un-shaded greenhouse (Hassanien et al., 2018).

The effect of PV modules mounted on top of a greenhouse, on the growth of strawberries and microclimate conditions as well as to estimate the generated energy have been estimated. One greenhouse was equipped with opaque photovoltaic (OPV) modules which accounted for 25.9% of the roof area, and the other was equipped with semi-transparent photovoltaic (STPV) modules which accounted for 20% of the roof area. The contents of soluble solids in strawberries in OPV and STPV greenhouses were 16.4 and 15.7 mg/g respectively, which were higher than those in unshaded samples. The quality and yield of the strawberry samples under the shade of OPV were better than those of the STPV shade (Tang et al., 2019).

Along with the aspect of renewable clean energy production, rainwater harvest will contribute to the sustainable development of regions. This procedure leads to the reduction of current challenges. This and the effect that this procedure has on productivity have encouraged researchers to research and develop these types of structures. High density and steep land value have driven people to maximize live able and productive spaces in urban settings. This includes the reinvention of roofs' functions extending from merely a protection from the elements to a platform housing sustainable building technologies such as green roofs, rainwater harvesting, and photovoltaic power generation. On one hand, researchers of different sustainable technologies are competing for funding, resources, space, and recognition. On the other hand, some of the green building rating criteria have an immense influence on decision-makers to choose only one between various sustainable building technologies (Sheng et al., 2011).

In another study at CIT College, rainwater harvesting was collected from rooftops which will be considered to be catchment areas from all Institutional departmental buildings and vehicle parking areas. First of all, required data are collected i.e. catchment areas &hydrological rainfall data. Water harvesting potential for the departmental buildings and vehicle parking area is calculated, and the tank capacity with a suitable design is considered. Finally, the Gutter designs, its analysis, first flush, and filtration mechanism are also dealt with detail. Using ulta chaata type of rainwater harvesting it provides clean water, energy and also provides environment shading at a lower cost. Each chaata takes about 1 square foot of area and one unit of ulta chaata can collect 60000 liters of water during the rainy season. It also captures energy with a maximum power of 1.5KW and it all depends upon climate conditions and the efficiency of solar panels (Vinayak et al., 2020).

Turkey is increasingly turning to renewable energy sources as a means to improve its energy security and curb dependence on imported gas from Russia and Iran. In research in Turkey it aims to analyze a PV power plant[1] type rainwater harvesting system (PVPPRWHS) in a 600 kW grid-connected solar photovoltaic (PV) power plant. An experimental rainwater harvesting was carried out in only 128 m^2 of Altınoluk Solar Power Plant, which has a surface area of 4320 m^2. This study showed that the potential for collecting rainwater from a small part of the PV plant is approximately 118 m^3 per year and that the harvesting system will reach 1646 m^3/year when applied to the whole plant (Aktas et al., 2021).

An exemplary study has been conducted to draw attention to the importance of evaluating the existing potential on the roofs of buildings. This research offers an evaluation of the existing solar energy and rainwater potential on the total roof area of the buildings in the Izmit district, which is a central district of Kocaeli province, one of the busiest centers of industry in Turkey. As a result of these calculations, the ratio of electrical energy that can be provided with photovoltaic systems on roofs to meet the annual electricity consumption of the district was found to be 203.581%, and the annual solar energy utilization rate for a family of 4 to bring 240 liters of daily use water temperature to 60°C with an 8 m2 collector area was calculated as 66%. In addition, the ratio of rainwater that can be collected from the total roof area of the existing buildings in the district to meet the domestic water consumed by the district was found to be 33.27% (Kaya, 2020).

The objective is to evaluate the potential savings from the use of the solar system for water heating and the rainwater system for purposes other than potable use to local conditions of sunlight and rainwater variability. Based on the economic evaluation, the economic efficiency of the proposed systems and the return on investment were calculated. The payback periods for the solar system used for hot water heating and the rainwater system used for non-potable purposes, accepting the local conditions, are 7 and 15 years, respectively (Bednárová et al., 2023).

Therefore, to achieve the final goal of this research, which is to investigate the multiple uses of solar panels on the roof of the greenhouse and collect rainwater, first, the studied area has been fully investigated and the climatic conditions, topology, and social status have been monitored. After studying the articles and similar research projects, at first, the modeling of solar panel installation on the greenhouse was done, and then the design related to piping, studs, and tanks was done on these greenhouses. In the end, the modeling results in energy production as well as rainwater collected and its volume estimation have been done.

One of the criticisms of solar power plants is their performance and their low efficiency, as well as the large space that is used to produce energy at the desired power. Therefore, multiple uses, especially the use on the roof of the structure, use as a cover and wall of the building, cover of canals and reservoirs, etc., can improve the challenge of using a lot of space. This problem will be solved to some extent, especially in areas that are facing a shortage of land, such as small and remote islands, or their lands have a high agricultural capacity.

The use of this panel as a greenhouse roof, the transparency of the panel that allows sunlight to pass through, and if rainwater is collected from the roof of the structure by installing gutters, piping systems, and tanks, this process leads to Increasing productivity and reducing consumption costs. In addition to this issue, it provides an increasing contribution to the issue of the environment and control of water shortage and successive droughts in the southern regions of Iran.

2. Materials and Methods

The purpose of the research is to estimate the amount of energy produced by the panels installed on the roof of the greenhouse and also to estimate the amount of water collected. For this purpose, the desired area has been checked by the mandatory conditions for installation, which have technical, economic, and social requirements. After the feasibility of installation and design of the greenhouse structure, the design of the piping system and tanks and rain collection surfaces have been done, and at the end, the

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[1] photovoltaic power station

results of the estimation of the produced energy and the collected water will be monitored. The conducted research has the advantage that the simultaneous use of the panel and the rain collection system at different installation angles, the optimal mode of simultaneous energy production, and rainwater harvest for the Khabr area have been investigated. The simulation performed is by the goals of the United Nations SDG, and in addition to the fact that its operational implementation has the least harmful effects on the environment; it will lead to the production of clean renewable energy in the region, as well as the prosperity of business. Examining the output of energy production modeling in this region will lead to the reduction of energy supply problems. Also, the rainwater harvest plan improves the performance of the process.

Most of the research that has been done in the field of rainwater harvest from the roof of the structure in Iran has only dealt with the topic of piping systems and tanks. In this research, in addition to using piping systems, solar panels, and estimating the appropriate angle in this panel, solar energy has also been used at the same time as rainwater harvest. The researchers of this project have designed and simulated a new type of greenhouse using the local conditions of the Khabr region and the environmental requirements.

The multiple uses of solar panels have grown significantly today in developed or developing countries. The merits of greenhouse crops have caused the development of this type of cultivation to be given much attention, as it is predicted that the current level of greenhouses will increase up to five times in the country's development horizon. This issue will increase energy consumption, and for this purpose, instead of using fossil fuels, we should look for alternative sources and also improve related processes to reduce energy consumption. The main energy consumption of greenhouses is related to machine operations, lighting, transportation, environmental condition control systems, and air conditioning systems.

2.1. Topology and Climate Monitoring of the Region

It should be kept in mind that Khabr village, with a geographic location of latitude 28.81 N and longitude 56.32 E, in addition to the environmental and tourism aspects, has a mountainous topology and the lands in it have a very good potential for cultivation due to the rainfall and suitable climate. Therefore, any operational project for water and electricity supply should not lead to land use change in this area and harm its rich protected areas. For this purpose and by using ArcGIS software, after obtaining the digital height data of different areas in this village, after taking the height of the areas, a part of the land in the plain and near Dashtab village, with a geographic location of latitude 28.85 N and longitude 56.36 E and altitude 2300m, as the desired area for Solar panel installation is suggested. After selecting the study area, the digital elevation method of 1960 points in the study area was obtained and the topology and slope of the area were estimated using ArcGIS software. Based on topological calculations, the said area has a slight slope towards the south (Figure 1).

Based on the data obtained from the solar radiation database, the amount of radiation in the Khabr region is about 2389.2 kWh/m^2 per year. It is important to check the sun path in the studied area. Using the data related to this factor, the maximum radiation angle in different seasons of the year and the shading effect are estimated. To prevent the panels from shading each other and according to the height of the panels, the appropriate distance between the panels was determined using equation (1) (Georg, 2012) of about 3 meters.

$$\beta_N = L - \delta \tag{1}$$

where L is the Azimuth, is the δ height angle and β_N is the tilt angle of the sun to the latitude of the region.

Another important factor in the performance of solar panels is the amount of time the effective radiation falls on the area. Figure 2 shows the average monthly radiation of the region. As can be seen, in most seasons of the year, from 8 a.m. to 5 p.m., you can use the sun's rays to produce clean and renewable energy. Even in May and June, this time has increased and is from 7 a.m. to 6 p.m. This wide period and high radiation power, which is generally less than 500 kilowatts per hour, can be an effective factor in production power and as a result, reduce the return time of investment.

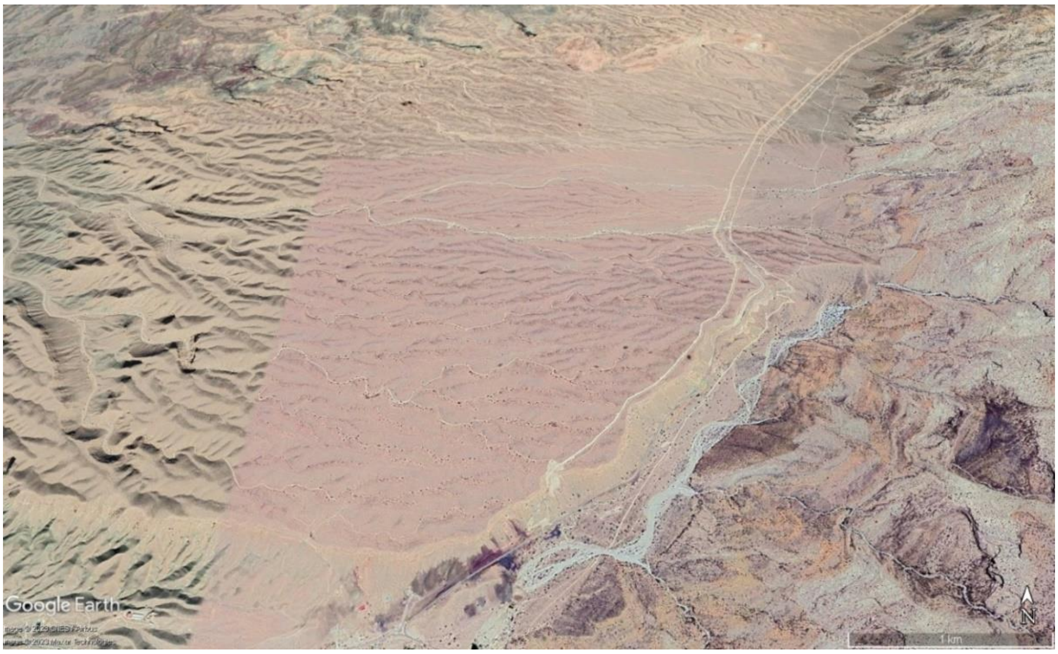
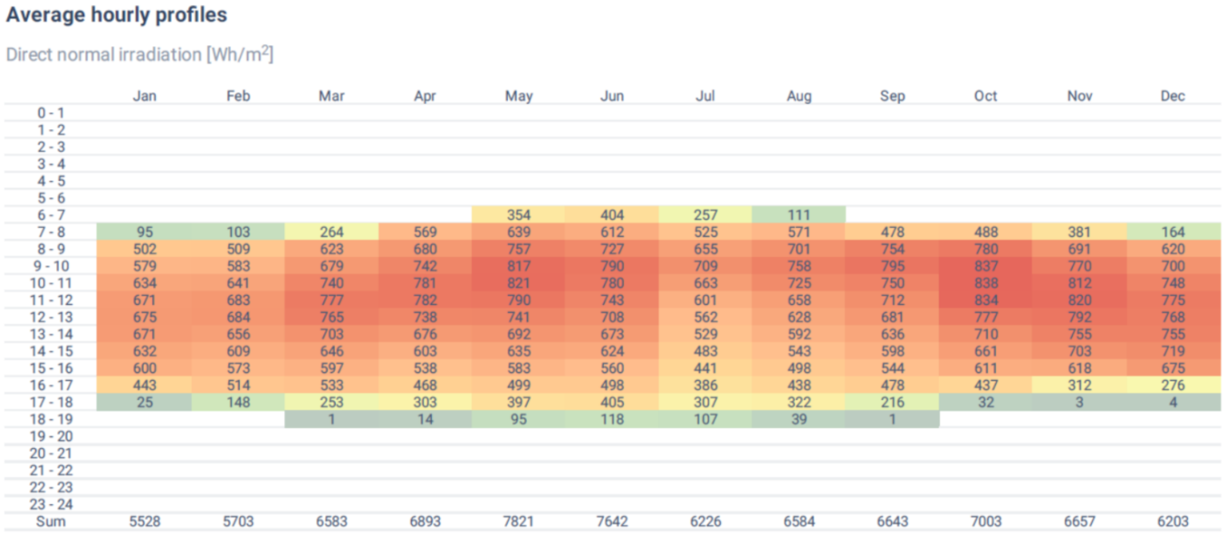


Fig. 2. Topology image of the investigated area for creating a greenhouse and rainwater harvest in Khabr village



Average hourly profiles

Direct normal irradiation [Wh/m^2]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
0 - 1												
1 - 2												
2 - 3												
3 - 4												
4 - 5												
5 - 6												
6 - 7					354	404	257	111				
7 - 8	95	103	264	569	639	612	525	571	478	488	381	164
8 - 9	502	509	623	680	757	727	655	701	754	780	691	620
9 - 10	579	583	679	742	817	790	709	758	795	837	770	700
10 - 11	634	641	740	781	821	780	663	725	750	838	812	748
11 - 12	671	683	777	782	790	743	601	658	712	834	820	775
12 - 13	675	684	765	738	741	708	562	628	681	777	792	768
13 - 14	671	656	703	676	692	673	529	592	636	710	755	755
14 - 15	632	609	646	603	635	624	483	543	598	661	703	719
15 - 16	600	573	597	538	583	560	441	498	544	611	618	675
16 - 17	443	514	533	468	499	498	386	438	478	437	312	276
17 - 18	25	148	253	303	397	405	307	322	216	32	3	4
18 - 19			1	14	95	118	107	39	1			
19 - 20												
20 - 21												
21 - 22												
22 - 23												
23 - 24												
Sum	5528	5703	6583	6893	7821	7642	6226	6584	6643	7003	6657	6203

Fig. 2. Hourly profile of radiation in different months of the year in the study region

The diagram of the sun path in the region shows that the maximum angle of the sun path is 85 degrees and the minimum is 36 degrees (Figure 3). Having sufficient knowledge of the sun path in the design of solar power plants, preventing the effect of shadowing and determining the optimal distance of solar panels is very important and is one of the requirements of any feasibility in solar projects (Zarezadeh, 2023a&b).

The amount of rainfall and climatic conditions of the region is the main data that is important and influential in choosing the installation location. The available data is obtained from the local meteorological station. According to the statistics obtained from the 20-year rainfall data of the region, the mean monthly rainfall of the region is 12 mm. The maximum amount of rainfall is in the winter seasons and the minimum amount of rainfall is in the summer, so that in some years, the summer rainfall was zero (Table 1).

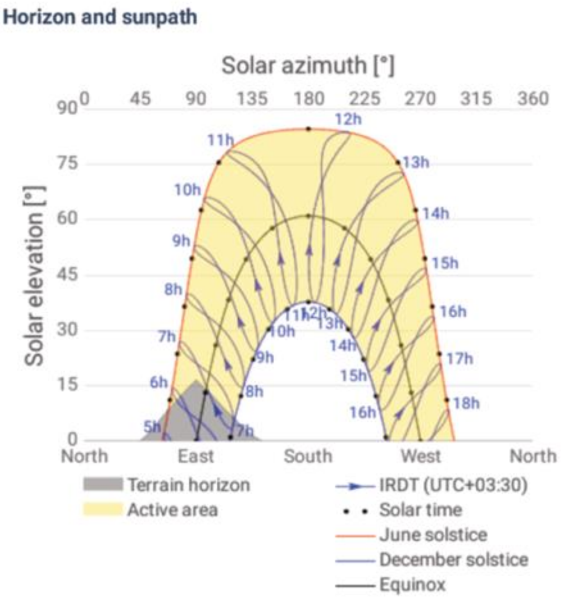


Fig. 3. Sun path in Khabr region

Table 1. Mean monthly rainfall of 20 years in Khabr village

No.	month	mean rainfall(mm)
1	January	22.74
2	February	2.65
3	March	23.35
4	April	26.22
5	May	10.24
6	June	1.36
7	July	0.84
8	August	6.37
9	September	0.17
10	October	1.67
11	November	11.72
12	December	24.48

2.2. Design of Greenhouse Structures

In many hot, dry, and semi-arid regions, rainwater harvest is important and necessary for drinking and agriculture. The technology of rainwater harvest from the roof of the structure is cheap and economical. Collecting rainwater from the roof of the structure, in addition to domestic water storage and agricultural purposes, is also useful for preventing soil erosion. Influential factors in the rainwater harvest system, most important factors are climate, technological knowledge and sustainable skills, land and sedimentology, and access to suitable structural materials (Muhirirwe et al., 2020). The amount of precipitation and its pattern is a very important factor for the feasibility of installing rainwater collection systems. To find the plumbing and piping system, the Thomas Box relation is used (Silvia et al., 2021):

$$q = \sqrt{\frac{d^5 \times H}{25 \times L \times 10^5}} \tag{2}$$

where, q is the discharge from the pipe in liters per second, d is the diameter of the pipe, H is the hydraulic water height difference in meters, and L is the total length of the pipe in meters.

The complete collection of rainwater from the roof of the structure is not possible, and in the optimal state, approximately 75% of it can be collected, and the rest cannot be used and collected due to evaporation and other wastes. For a tank that has inlets and outlets, the relevant equations are equal to:

$$V_{end} = V_{start} + R + P - E - S - L - Y \tag{3}$$

where V_{end} and V_{start} are the volume of water in the tank at the beginning and end of each measurement period, R is the amount of rainwater entering the tank, P is the direct entry of rainwater into the tank, E is the amount of evaporation of rainwater in the tank, S is the amount of fall from the rainwater tank due to overflow, The amount of excess water that overflows the tank. Its calculation is based on the volume of the tank, the remaining water from last month, and the amount of rainfall in that month, L is the loss of leakage (or leakage) and Y is the output of the tank. In the case that the tank is covered, direct rainwater enters the tank, evaporation is considered zero and losses can be ignored and the relationship will be as follows (Mashford and Maheepala, 2015):

$$V_{end} = V_{start} + R - S - Y \tag{4}$$

Since the structure of the greenhouse is designed for the cultivation of all kinds of plants and shrubs and includes equipment such as a ventilation system, irrigation pipes, cultivation floors, fog maker, artificial light lamps, and heating system, and therefore the dimensions of the structure should be proportional to This is the equipment. Therefore, the dimensions of each greenhouse are 10 x 50 meters and the height is 5 meters. Besides the aspect of renewable and clean energy production, rainwater harvest is studied in the area. According to the useful area in the study area, 80 greenhouse structures with the stated dimensions have been designed (Figure 4). To make optimal use of sunlight for energy production and also for exposure of the plants grown in the greenhouse, the orientation of the designed greenhouses is east-west and for the optimal use of solar panels, the narrow side of the roof of the structure is designed exactly in the south direction.

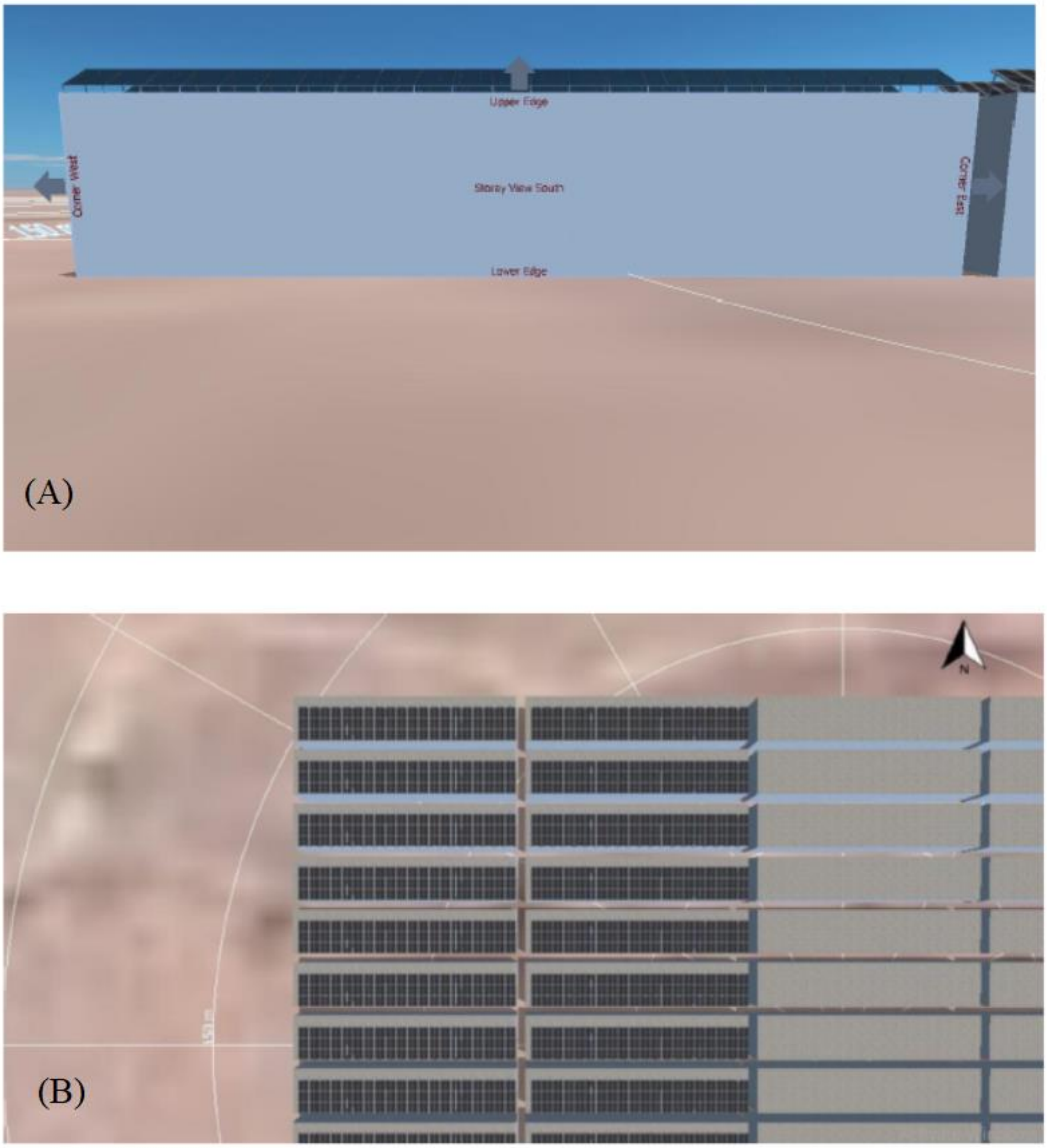
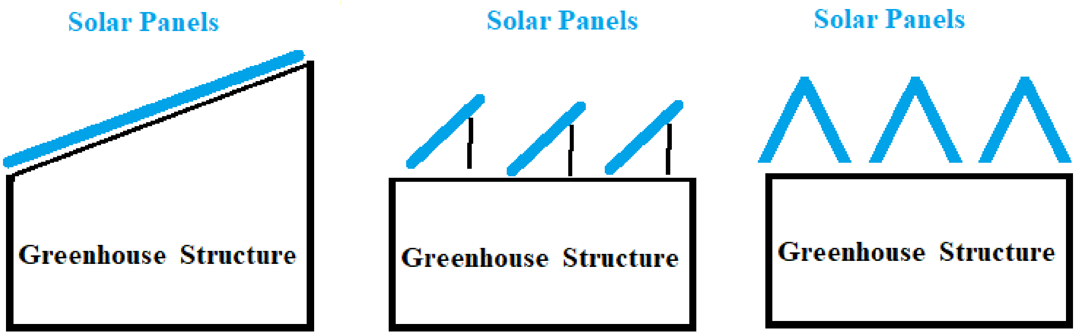


Fig. 4. The side view (A) and top view (B) of the greenhouse structure and solar panels installed on the roof of the structure.

2.3. Modeling of the Panels Installed on the Roof of the Greenhouse Structure

According to the type of designed structure, three types of panel installation methods have been simulated using PVSol software version 2021. Three different installation scenarios are considered, a south-facing panel, an east-west panel (delta wing), and a flat face-mounted panel on the roof with a 28° azimuth angle (Figure 5).

The reason for using three different scenarios is to reach the optimal point. This optimal point includes the appropriate amount of energy production, and the number of panels, considering that their mass affects the roof of the structure, as well as reducing the piping and gutter system. The number of panels should be such that their mass does not lead to a lot of pressure on the roof of the structure and as a result, the roof of the structure is not destroyed under pressure. To prevent the software from being interrupted during execution, and considering the high graphics and the large volume of data, the simulation was executed in several separate parts and the results were combined at the end. All the panels and converters used in the simulation are the same and have the same parameters (Table 2).



(A) (B) (C)

Fig. 5. A view of how to install a solar panel on the roof of the structure, in the flat face mode at an angle of 28 degrees relative to the azimuth (a), installed at an angle of 28 degrees relative to the azimuth (b), delta wing mode, east-west (c)

Table 2. Specifications of the solar panel used in the simulation (JA Solar Panel, Jam85 model)

No.	Parameters name	Quality/Quantity
1	Cell Type	Polycrystalline
2	Voltage at the maximum power point	38.25 V
3	current of maximum power	9.02 A
4	Open Current Voltage	46.07 V
5	Short circuit Current	9.5 A
6	Nominal power	345 W
7	Fill Factor	78.83 %
8	Efficiency	17.19 %
9	Panel width	996 mm
10	Panel length	2015 mm
11	Area of panel	2.01 m^2
12	Panel mass	22.7 Kg
13	Output heat coefficient	-0.37 %/K

For this purpose, three different scenarios were used to simulate the installation of panels on the roof of each designed greenhouse structure. Table 3 shows the number of panels and output power of each scenario on the roof of each greenhouse structure.

Table 3. The number of panels and the output power of the panels on each of the greenhouse structures in the study area

Panel Direction	Number of panels	Output power (kw)	Total panel mass (kg)
South direction	86	52.4	1952.2
East-West	120	37.6	2724
Flat face mounted on the ceiling with an angle of 28 degrees to the azimuth	144	74.6	3268.8

According to the above table and also the type of installation on the structure, the most optimal installation mode in terms of number is the flat installation mode.

2.4. Estimation of Rainwater Harvest

To determine and estimate the amount of rainwater harvest, the product of the catchment area multiplied by the average rainfall is the coefficient of performance of the roof covering in scattering and evaporation. To find the volume of the tank, this volume is also expressed based on the stated equation (3). To measure the volume of the tank, it should be noted that it depends on the way of consumption and how much this consumption is. For a month, it is equal to (Monteiro et al., 2023):

$$V_t = V_{t-1} + \left(Rainfall - Consumption\, Rate \right) \tag{5}$$

where V_t is the estimated volume of water remaining in the tank at the end of the month, and V_{t-1} is the volume of water remaining in the tank from the previous month. If the tank is initially empty, *Vt-1* is zero. If after each month V_t is more than the volume of the tank, the excess water is drained from the pipe. The design of the building's roof structure has a great impact on the amount of rainwater absorption. Monthly temperature changes are related to rainfall in the region.

To determine the runoff coefficient, the entire experimental method must be checked.

Based on the climatic conditions of the region, the runoff coefficient is obtained using the following equation (Monteiro et al., 2023):

$$C_M = \frac{\left\lfloor 0.016\left(P_M + R_M\right)\right\rfloor}{\left(2T_M - T_{M-1}\right)^{1.2}} \qquad (6)$$

where C_M is the runoff coefficient in month M, P_M rainfall in month M in mm, R_M irrigation in M^{th} month in mm, T_M average air temperature in month M in Celsius, and T_{M-1} average air temperature in month M-1. The amount of water humidity has a great effect on the return water capacity. The amount of the runoff coefficient is obtained experimentally with the following relationship (Monteiro et al., 2023):

$$C = \frac{V_{runoff}}{\left(P + R\right) \times A} \qquad (7)$$

where V_{runoff} is the volume of collected water, P is the rainfall in mm, R is the irrigation volume in liters, and A is the roof area in square meters.

To ensure the safety of the reservoir and to ensure the working condition of the reservoirs, generally, the volume produced for rainwater collection is considered to be 20% more than the calculations (Beqaj et al., 2020).

2.5. Piping System and Tanks

The estimate related to the piping system in the tanks, the roof of the greenhouse, and the water transfer from the roof to the tanks has been obtained using Thomas Box relationships and different standards. According to the estimates related to the collected water, and the dimensions of the required structure and piping, which is 30 meters, the maximum internal diameter, water flow rate, and pressure drop have been estimated based on different standards (Table 4).

The research process carried out in this section in the figure 6 is visible. The workflow for doing this is presented in the flowchart. The results of these actions can be seen in the results section and analyzed in the conclusion section.

Table 4. The dimensions of the pipes required for the rainwater harvest system on the roof of the structure based on the climatic data and the dimensions of the structure (Parisher and Rhea, 2002)

No.	Related Standard	Piping dimensions	Inner diameter of the pipe(mm)	Water velocity(m/s)	pressure loss (bar)
1	DIN 2448	DN40	43.1	1.903	0.2941
2	JIS-SGP	50A	52.9	1.26	0.104
3	ANSI Sch40	NPS2	52.50	1.283	0.108

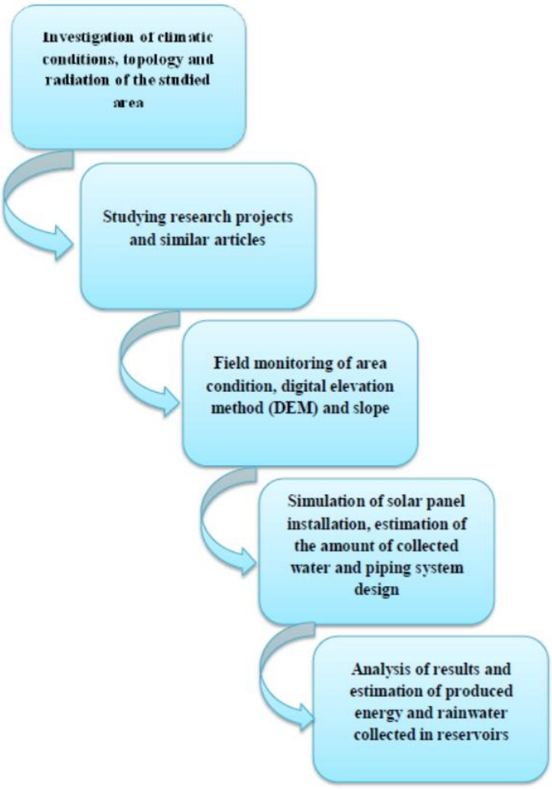


Fig. 6. Flowchart of the research process

3. Results and Discussion

The goal of leading research has been to use multiple sources of energy, water, and food at the same time and achieve sustainable development, considering the importance of the ecosystem of the Khabr tourism region, in line with providing sustainable energy. Therefore, the objectives have been examined separately in these sections. The first goal of the research is to achieve renewable solar energy. However according to the climate of the region and suitable lands for cultivation in Khabr village, using these lands without using them for the main purpose, which is cultivation, leads to the deviation of the research from its original path. The energy obtained on the roof of each of the greenhouse structures was obtained with three installation scenarios and the data is available in Table 5.

Table 5. Simulation output of the technical performance of solar panels installed on the roof of the greenhouse structure

Panel Direction	Output power (kw_p)	Energy yield (kwh/year)	Performance Ratio (%)	Shading reduction (%/year)	Number of panels	Number of inverters
South direction	4942.3	8909973	88.1	0.9	6966	162
East-West	5929.2	11327886	89	0.9	9720	324
Flat face mounted on the ceiling with an angle of 28 degrees to the azimuth	9404.4	17227057	86.1	1.2	11664	182

According to the climatic conditions of the region, the amount of energy produced in all three scenarios is suitable, which is suitable compared to the technical data of other places. The performance ratio in all three installation modes is suitable and more than 85%, and according to the topology of the area, where there are no tall buildings around the desired position, the shading reduction factor, which hurts the output power of solar panels, is low 1% per year. In terms of structural dimensions, the flat face-mounted installed layout has the largest number of panels and has an optimal space for installation, and therefore the output power and electrical energy produced have the highest value in the three scenarios.

The performance ratio of the solar power plant is quantitatively variable compared to the environmental conditions and changes in different months according to the type and amount of radiation, the climatic conditions of the region, etc. The important thing about installed panels is their performance ratio. The average of this coefficient for the whole year is 88%. But its amount increases significantly up to 95% in the cold months of the year and reaches its lowest value of 85% in the hot months of the year, which indicates the proper performance of these panels, especially in the cold seasons of the year. The appropriate radiation of the area and its appropriate temperature has a significant effect on the panels and leads to an increase in their efficiency.

In addition to absorbing energy through solar radiation, the panels installed on the roof of the structure will also lead to a change in the temperature around them. Temperature changes caused by installing panels on the roof of the structure should not lead to large changes. According to Figure 8, these changes are not so noticeable and significant, and therefore will not have much effect on the negative performance of greenhouse cultivation.

Along with the results and influencing factors in choosing the position of solar panel installation, estimating the amount of radiation energy received by each panel is very important. In addition to the performance of the output of energy produced from solar panels, this issue also affects the performance of cultivation in the greenhouse. It can be seen in Figure 9 that the minimum amount of radiation is 110w/m^2. The minimum radiation is in winter and the maximum is in June. The total annual radiation is equal to 2186 w/m^2.

In addition to the aspect of clean energy production, the use of seasonal and permanent rains in the Khabr tourism area can be of great help in preventing water wastage and in other words, the use of rainwater, which has been significantly developed at the level of countries today. The total effective area of the roof of the greenhouses and the amount of rainfall are influential factors in calculating the amount of water collected and designing the reservoirs and piping system. The amount of water collected from the roof of the entire designed greenhouse complex is presented in

Table 6. According to these data, which were calculated and estimated based on the average rainfall of the last twenty years, the minimum volume of the tank required to collect all the rainwater from the roof of the greenhouse in the final state ideally is 61,000 cubic meters.

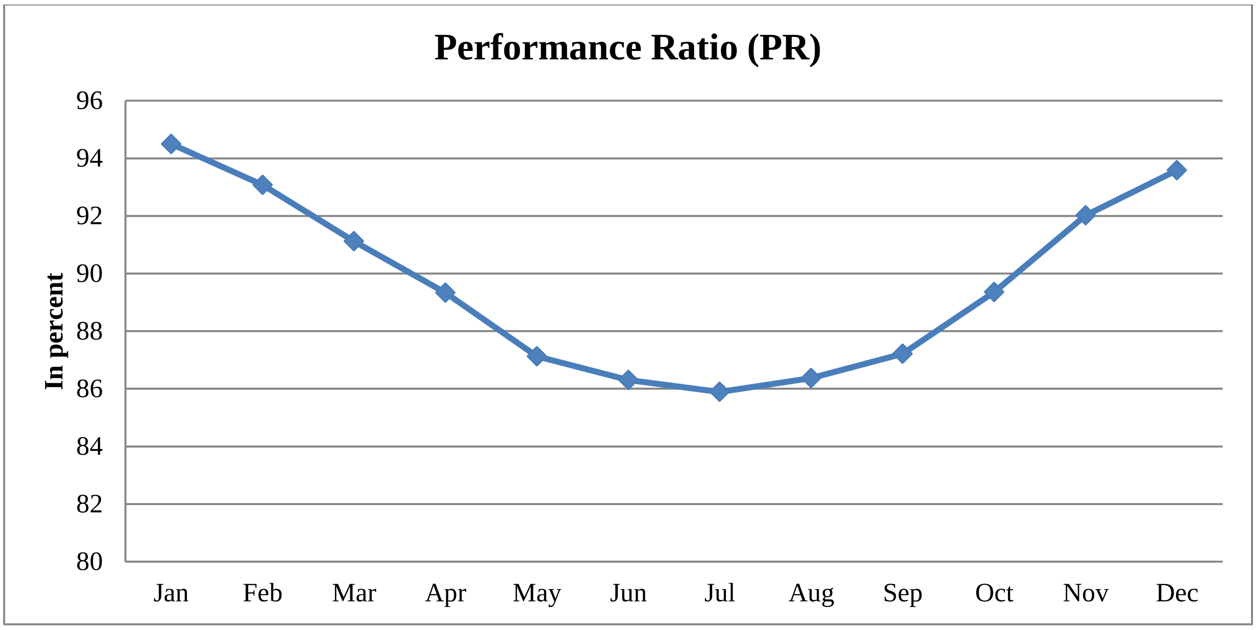


Fig. 7. Monthly performance ratio of panels installed on the roof of the greenhouse structure in Khabr region

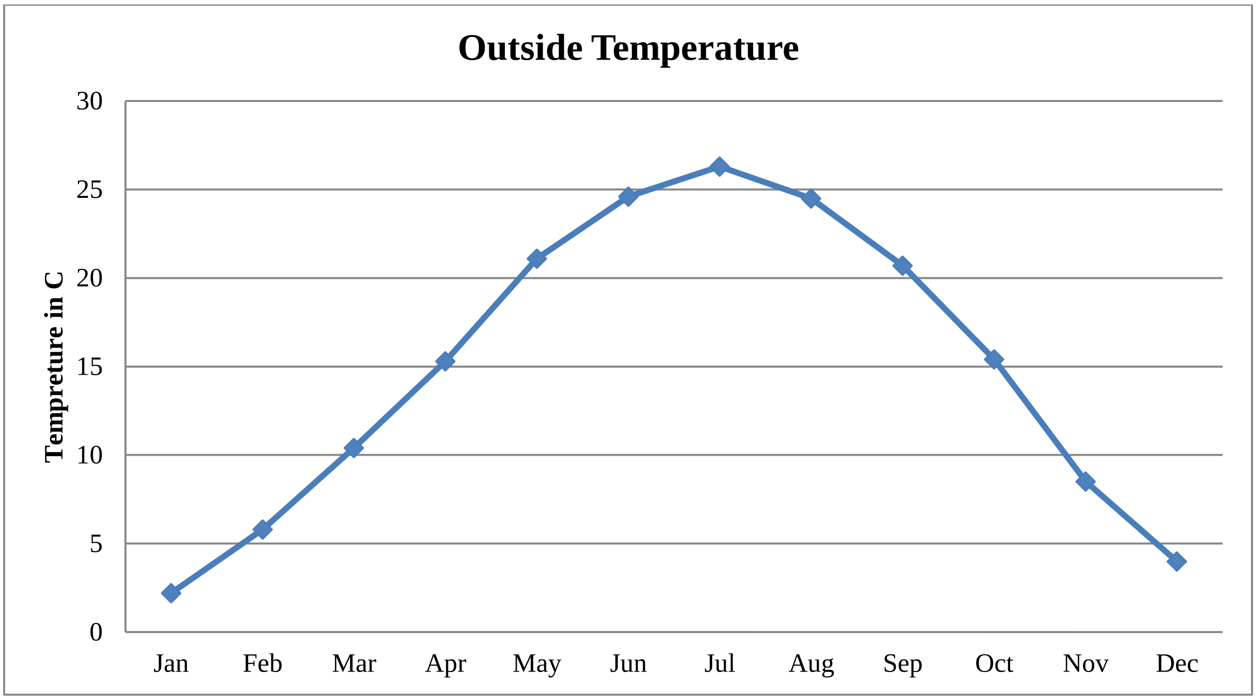


Fig. 8. Ambient temperature around the solar panel in different months of the year on the roof of the greenhouse structure in Khabr region

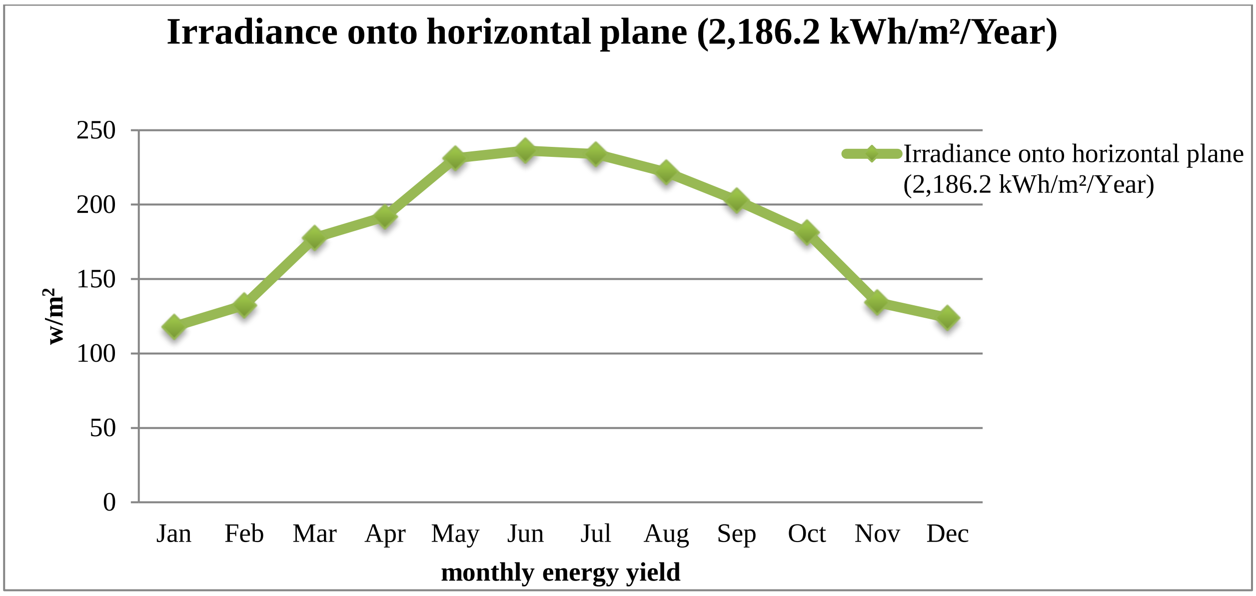


Fig. 9. The yield of energy received in each of the panels installed on the roof of the greenhouse structure in different months of the year in Khabr region.

Of course, it should be kept in mind that the estimated volume depends on many parameters, including sudden changes in climatic conditions, seasonal monsoon rains, and the amount of water used to supply the water required by the greenhouse.

Table 6. The amount of water collected from the roofs of structures in different months of the year in Khabr region

No	Month	Rainwater harvest (m^3)
1	January	9211.90
2	February	8365.09
3	March	9457.71
4	April	10622.34
5	May	4150.44
6	June	550.8
7	July	343.44
8	August	2580.18
9	September	70.87
10	October	677.93
11	November	4749.06
12	December	9915.45

According to the estimation of the collected rainwater, and the possibility of water splashing from the roof and tanks, in the maximum possible case, 75% of the water is in Table 6.

4. Conclusion

The most suitable way to install the panel is to install it on the roof with a slope of 28 degrees, which is the best in terms of energy production and rainwater harvesting, this type of installation will also create a windbreak and protect against fast winds. It shows better resistance and stability. Installing a windbreaker can prevent the penetration of cold air outside and the exit of heat inside the greenhouse in the form of convection. There are several advantages to installing on the roof of the greenhouse with an angle of 28 degrees:

1- Due to the complete installation on the roof, a windbreak has been created and there is a more suitable stability against the wind.
2- Installation in this case requires less metal structure and metal bases, as a result, the mass is less and the mass of these base structures is less than the total mass.
3- Since in this case the panel is installed directly on the roof, the installation arrangement is optimal the distance between the panels and the structure will be reduced and this space will be used properly.
4- Finally, the use of this system will lead to a reduction in the amount of piping and, as a result, excess construction costs and future maintenance costs.

The amount of water used for crop is about 5,000 cubic meters per hectare for each crops period (Hirich and Chouk-Allah, 2017; Hong et al., 2022).

Generally, the growing periods of summer crops in the greenhouse are 120 to 140 days. This means that for one year, the amount of water used to produce summer crop is about 15,000 cubic meters per hectare in one year. Considering the surface area of the simulated greenhouse, which is about 1.94 hectares, and therefore the water consumption for one year is about 29100 cubic meters. Based on this, it is possible to supply the water needed for greenhouse cultivation with half of the collected rainwater.

According to the research, about 1.6 megajoules of energy will be consumed for every 2 kg for one year (Firoozi et al., 2014; Djevic, 2008). According to the size of the land and the total area of the greenhouse in this study, which is about 1.94 hectares, the average production of plants in this amount of land in the greenhouse is about 1450 tons. As a result, the amount of energy required for this amount in one year will be around 1.164 GJ, which is equivalent to 323333 kWh. With the addition of other electrical energy uses, it can be said that the renewable energy produced during the day without rain and in clean weather can easily supply the energy required by the greenhouse, and in addition, the excess energy produced is connected to the city's electricity and be sold From the point of sale of produced electricity, the cost of electricity can be provided at night or during hours when it is not possible to produce electric energy from solar panels, and the surplus is used as an income for the greenhouse owner.

5. Conflict of Interest

No potential conflict of interest was reported by the authors.

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