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# Economic Analysis for Performance of Photovoltaic-Direct-Powered Solar Domestic Hot Water Systems Using Experimental Evaluation in Iraq

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## Abstract

Photovoltaic (PV) systems can be used in a wide range of applications because of a significant drop in cost over the last ten years for PV modules. Because PV solar panels are low-cost and have a simple design that just requires sunshine to work, they can be used to power loads that are directly linked to PV panels. Because of this, it is a more alluring option for applications involving water heating.

In this work, experimental evaluation has been done for photovoltaic-direct-powered solar domestic hot water. When evaluating performance, the value of power generated by PV panels is crucial. As solar radiation rises, its value rises as well. The PV heater tank's inside water temperature reached a maximum of 83.50 °C. A family of three members used 131 liters of water at a flow rate of 2 L/m. The maximum power delivered to the heating element was 1188 W, and the maximum power generated by PV panels was 1240 W. Based on the specifications of the 1500W heating element utilized, about 312W of electricity is lost during operation. Calculations revealed that the system's electrical efficiency was 22.3%. The system required 8.6 years of payback time to recoup its initial expenditure. This system can be considered an alternative to STWH to overcome the problems of impurities in the water used for domestic purposes, which reduce the efficiency of STWH systems, and to overcome heat losses when transporting water through pipes. These systems are less susceptible to damage compared to STWHs. Based on these results, it is advised to utilize a direct- connected photovoltaic water heater system (DPVWH) in cold weather because of its ease of use and efficiency, as it is a technology that operates during daylight hours.

**Keywords:** PV Solar System; Photovoltaic Water Heater; Solar Energy Cost; PV Efficiency.

**الخلاصة:** يمكن استخدام الأنظمة الكهروضوئية (PV) في مجموعة واسعة من التطبيقات بسبب الانخفاض الملحوظ في تكلفة الوحدات الكهروضوئية على مدى السنوات العشر الماضية. نظرًا لأن الألواح الشمسية الكهروضوئية منخفضة التكلفة ولها تصميم بسيط يتطلب فقط ضوء الشمس للعمل، فيمكن استخدامها لتشغيل الأحمال المرتبطة مباشرة بالألواح الكهروضوئية. ولهذا السبب، فهو خيار أكثر جاذبية للتطبيقات التي تتضمن تسخين المياه.

في هذا العمل تم إجراء تقييم تجريبي لأنظمة تسخين المياه المنزلية التي تعمل بالطاقة الشمسية الكهروضوئية. عند تقييم الأداء، تعتبر قيمة الطاقة التي تولدها الألواح الكهروضوئية أمر بالغ الأهمية. ومع ارتفاع الإشعاع الشمسي, ترتفع قيمته ايضاً. وصلت درجة حرارة الماء الداخلي لخزان السخان الكهروضوئي إلى 83.50 درجة مئوية كحد أقصى. استخدمت عائلة مكونة من ثلاثة أفراد 131 لترًا من الماء بمعدل تدفق 2 لتر/دقيقة. كانت الطاقة القصوى التي تم توصيلها إلى عنصر التسخين 1188 واط، وكانت الطاقة القصوى المتولدة بواسطة الالواح الكهروضوئية 1240 واط. بناءً على مواصفات عنصر التسخين 1500 واط المستخدم، يتم فقدان حوالي 312 واط من الكهرباء أثناء التشغيل. وأظهرت الحسابات أن الكفاءة الكهربائية للنظام بلغت 22.3%. يتطلب النظام 8.6 سنوات من وقت الاسترداد لاسترداد نفقاته الأولية. يمكن اعتبار هذا النظام بديلاً لنظام STWH للتغلب على مشاكل الشوائب الموجودة في المياه المستخدمة للأغراض المنزلية والتي تقلل من كفاءة أنظمة STWH، وللتغلب على فقدان الحرارة عند نقل المياه عبر الأنابيب. تعتبر هذه الأنظمة أقل عرضة للضرر مقارنة بأنظمة STWH. وبناء على هذه النتائج ينصح باستخدام نظام سخان المياه الكهروضوئي المتصل بشكل مباشر DPVWH في الطقس البارد لسهولة استخدامه وكفاءته، فهي تقنية تعمل خلال ساعات النهار.

## Nomenclature

| Symbol | Title | Units |
|---|---|---|
| $I_{DC}$ | DC Current | Amp |
| SR | Solar Radiation | $W/m^2$ |
| $G_T$ | Total global solar radiation intensity | $W/m^2$ |
| P | Power solar radiation | W |
| $P_{max}$ | Maximum power produced by PV panels | W |
| Ppv | Photovoltaic power | W |
| R | Resistance of DC heating element | ohm |
| T | Temperature | °C |
| $V_{DC}$ | DC Voltage | V |
| $A_{pv}$ | Area of the PV panel | $m^2$ |
| FR | Flow Rate | L/m |
| n | Number of PV panels in the module | - |
| $\eta_{PV}$ | The PV module's electric efficiency | % |
| $Q_{load}$ | Quantity of electricity needed per day | kWh/day |
| $m_w$ | Quantity of water needed for the day | kg/day |
| $C_{pw}$ | Specific heat of water | kJ/kg˚C |
| $T_{hot}$ | Final temperature of heated water | ˚C |
| $T_{cold}$ | Initial temperature of heated water | ˚C |
| CE | he cost of electricity per kWh | $/kWh |

## Abbreviations

| Symbol | Title |
|---|---|
| DC | Direct Current |
| AC | Alternating Current |
| DWH | Domestic Water Heater |
| DPVWH | Direct- Connected Photovoltaic Water Heater |
| CHP | Combined Heat and Power System |
| STWHs | Solar Thermal Water Heaters |
| PV | Photovoltaic |
| DEWH | Domestic Electric Water Heating System |
| PVWH | Photovoltaic Water Heater |
| TRNSYS | Transient System Simulation Tool |
| PV/T | Hybrid Photovoltaic/Thermal |
| MPPT | Maximum Power Point Tracking |
| GSMNP | Great Smoky Mountains National Park |
| NIST | National Institute of Standards and Technology |
| FSEC | Florida Solar Energy Center |

# 1. INTRODUCTION

World resources are being depleted as a result of growth in population and development endeavors[1]. Because energy sources are essential to meeting the global population's needs, they must be carefully considered [2]. For the benefit of the future of the planet, it is imperative to use eco-friendly energy sources[3][4]. In this regard, it is vital to take into account eco-friendly renewable energy sources as solar, wind, hydropower, and geothermal energy[5]. Solar energy, however, might be the greatest choice for the future world for many reasons: First, among renewable energy sources, solar energy is greatest plentiful[6][7]. It is a readily available source of energy and free[8]. Secondly, it is a sustainable energy source that yields higher and more consistent production efficiency than other energy sources, making it a promising global energy source[9]. The planet receives solar energy in a variety of forms, including light and heat[10][2]. Technologies that transform sunlight into usable types of energy fall into two main categories. First, solar photovoltaic (PV) modules use direct solar energy conversion to produce electricity. Second, concentrated solar radiation is used in solar thermal power systems to create steam, which powers a turbine that generates electricity[5][11].

Over the past ten years, there has been a notable decline in the cost of PV modules, which has created new opportunities for the use of PV systems in many applications[12]. As an alternative to traditional systems that rely on fossil fuels or solar thermal energy, this has prompted researchers to investigate and evaluate the performance of various PV applications. Historically, efforts to reduce the energy used for home water heating have primarily focused on solar thermal water heaters (STWHs). Nonetheless, STWHs frequently experience collector freezing and overheating problems. From a technical point of view, PV water heating is appealing since it fixes these traditional STWH control issues. Furthermore, PV systems need less sunlight than STWHs, which must first overcome the collector heat loss to provide a useful output[13]. Because of the many details of STWHs, such as the maintenance of the evacuated tubes for it, as well as the pipes extending from the heater to the source consumption and thermal insulation, and the maintenance of the water circulation pump if necessary, it is possible to provide a tariff for electrical energy consumption based on the state's price, which is almost twice as much without the calculated cost of maintenance. Additionally, the STWH will not function if any of its vacuum tubes are damaged or destroyed. On the other hand, if the PVWH's panels crack, it can still function, albeit less effectively than it did before[14]. Photovoltaic systems have a very simple design that consists of a PV module and a load (direct feeding) that only needs sunlight to work[15]. Water heating is one interesting use for PV systems, especially when PVWH system is put in place. PV modules and electric heating components are used in the PVWH system. The heating element submerged in the water tank is supplied with power either directly or indirectly by the PV modules[16]. Conventional DWH system constitute a major global contributor to the building sector's greenhouse gas emissions and energy consumption[17].

As a result, the building sector's energy costs and carbon footprint can be significantly decreased by using PV energy for water heating. Thus, a new and promising direction in the search for ecologically acceptable and sustainable solutions is the study and assessment of PV water heating systems.

The utilization of PV modules coupled to electric heating elements for home hot water has been analyzed by many researchers.

Fanney and Dougherty[18] have developed a patent for a photovoltaic water heater that used resistive elements coupled to a resistor controller to match the load's current-voltage characteristics to the PV panel. The goal was to maximize power production in a variety of weather conditions without requiring an MPPT controller. Dougherty et al.[19] studied a solar PVWH system (a two-tank system) erected in the GSMNP. The setting up of 1.9 L/min rated aerators resulted in a sizable decrease in hot water and auxiliary energy usage, these efforts had mixed success. Dougherty and Fanney[16] reported that two military housing buildings in Okinawa, Japan installed a two-tank PVWH system. In both the first and second systems, electrical energy was substantially lower than anticipated at 25.8% and 28.0%, respectively. Prototype single-tank systems were also built and evaluated at NIST and FSEC; the energy needed percentages were 49.0% and 51.8%, respectively. Pokorny et al.[20] investigated a recently designed and constructed prototype of a glazed liquid PV/T collector, which was constructed with a contemporary PV cell encapsulation technique. The analyses further confirmed that it is not economically sensible to enhance insulation thickness. Only 1% more thermal energy is produced as a result of the thicker insolation. Matuska and Sourek[21] examined the direct connection of a solar PV array to DC resistive heating elements immersed in the hot water tank in a solar PV water heating system. In all tested climates, the efficiency of a PV water heating system including MPPT varies from 13 to 15%, while a simple system without MPPT only performs between 10 and 11%. Systems using photothermal energy have an overall efficiency of between 35 and 68%. Mohammadi Sarduei et al.[22] investigated the performance of a PV/T solar water heater in four different Iranian towns by using the TRNSYS tool. The cities generated an average of 4.65 and 2.67 kWh of electricity per day during the summer and winter, respectively. The PV/T system's greatest daily average thermal energy was 16 kWh, with a 50% solar fraction. Elnaggar et al.[23] conducted a simulation by using TRNSYS software to investigate the differences in solar energy harvesting efficiency between two climatically different places utilizing PV systems and solar thermal collectors.

Hamdoon et al.[24] studied the use of numerical simulations for the thermal and electrical performance of a PV/T solar domestic hot water system for a five-person household in Mosul, Iraq. Alayi et al.[25] published the topic of simultaneously producing heat and electricity with a solar micro-CHP system was examined. The building's electrical charge is provided by the solar PV system, and the thermal charge needed to heat the building's water is supplied by the solar water heater, likewise the solar collectors. Al-Hamadani and Yaseen[26] conducted an experimental study on solar desalination using a Multi-Stage Effect Photovoltaic Heater, Solid Still, using paraffin as a phase transition medium, and a DC water heater, to determine the increase in freshwater output. Yildiz et al.[27] examined the effects of various daily hot water demand profiles, PV, and DEWH size on the possibility of PV use excess using real-world data and the thermal energy modeling tool TRNSYS. The primary goal of the analysis was to determine whether it would be feasible to store and use excess production of PV in DEWH. Clift and Suehrcke[28] investigated the possibility of heating water using excess photovoltaic power by utilizing the hot water storage tank as an inexpensive thermal battery by using TRNSYS. Thirteen field installations' measurements are used to validate the modeling results. Badran and Obeidat[29] studied the integration of a PV/T trickle system with a traditional solar heater to determine the instantaneous electrical, thermal, and overall efficiencies of the PV/T system, as well as the productivity of the desalinated water, energy balances on collector and desalination modes must be performed. Hachchadi et al.[17] examined the efficiency that which the DPVWH system connects the heating element and PV array directly under two various climatic conditions. TRNSYS and MATLAB/Simulink software were used to generate simulation models to assess the operation of a PV system that was linked direct to the heating element for a whole year. An experimental configuration was used to validate this simulation model.

The study area is Iraq, Wasit (32.514° N - 45.819° E). Based on the city's winter conditions, the water is too cold to be utilized without a heater. To address some techno-economic challenges and potentially advance the idea in Iraq, this research will investigate the production of hot water in Wasit during the chilly winter months through solar energy by using a DPVWH system. The current study aims to evaluate the DPVWH system which uses only solar energy for household use during solar noon experimentally. It only uses a fixed resistance element (heating element) that is directly connected to the photovoltaic panels as an electrical load using direct current. The purpose of the work is to reduce costs and simplify the solar system as a whole. The feasibility of this system is being verified under the city's weather conditions to find an alternative to STWHs. This is considered almost the first PV system in Iraq for heating water that is being evaluated to be an alternative to STWH systems to overcome the problems of impurities in the water used for domestic purposes, which reduce the efficiency of STWH systems, and to overcome heat losses when transporting water through pipes.

## 2. MATHEMATICAL EQUATIONS

Several factors, including the system's design and technical specifications, as well as the surrounding environmental conditions, affect the solar PV system's performance[30]. To evaluate the system performance in this article,
The power solar radiation (W) that hits the surface of the inclined PV panels was calculated from the following equation[23]:

$$P = G_T * n * A_{PV} \quad (1)$$

Consequently, the power produced by PV solar panels (W) is given by[31]:

$$P_{PV} = I_{DC} * V_{DC} \quad (2)$$

The resistance (ohm) value of heating element is calculated by the equation[17]:

$$R = \frac{V_{DC}}{I_{DC}} \quad (3)$$

The PV module's electric efficiency is determined by[32]:

$$\eta_{PV} = \frac{P_{max}}{G_T * n * A_{PV}} \quad (4)$$

The payback period is the amount of time (measured in years) required to recover the initial investment. The time of energy recovery is the ratio of the total embodied energy used in the production of photovoltaic systems to the annual energy produced by photovoltaic systems[33]. Which is given by[34]:

$$Payback\ period(in\ years) = \frac{Capita\ investment}{Anual\ saving} \quad (5)$$

$$\text{Annual saving} = 182 \times CE \times Q_{load} \quad (6)$$

182 days, assuming that the need to use hot water is 6 months.

$$Q_{load} = m_w \times C_{pW} \times (T_{hot} - T_{cold}) \quad (7)$$

# 3.EXPERIMENTAL WORK

## 3.1. Direct- Connected Photovoltaic Water Heater (DPVWH)

Solar water heaters powered by photovoltaic cells are one example of renewable energy uses. A DPVWH system does not require an inverter to transform the DC power produced by the photovoltaic array into AC power, unlike the great majority of solar photovoltaic uses. It uses a direct connection between the heating element and the PV array[17]. It is an off-grid, PV-direct, indirect method for implementing solar water heating. The direct current (DC) power provided by solar photovoltaic modules is utilized to feed one DC resistive element that is immersed in a water storage tank directly and is 100% generated by solar energy[16][19]. Direct-coupled photovoltaic systems have several benefits, including ease of installation, reduced maintenance and investment costs, and simplicity[35].

## 3.2. Main parts of DPVWH

The system consists of simple components that include four photovoltaic panels connected in parallel with a fixed voltage of 48 V, and the power of the single panel is 540 W , as shown in Figure 1. The total area of the panels is 10.54 $m^2$. The system was installed at a tilt angle of 25˚ from the horizon and oriented towards the geographical south of the city. Table 1 shows the detailed parameters of PV modules.


Figure 1 PV Panels

Table 1 The PV module's parameters

| Parameter | Value |
|---|---|
| **Maximum power $P_{max}$** | 540 W |
| **Maximum power voltage $V_{pm}$** | 41.65 V |
| **Maximum power current $I_{pm}$** | 12.97 Amp |
| **Open circuit voltage $V_{oc}$** | 49.50 V |
| **Short circuit current $I_{sc}$** | 11.14 Amp |
| **Temperature coefficient of voltage $\beta_{Voc}$** | -0.284%/˚C |
| **Temperature coefficient of current $\beta_{Isc}$** | 0.050%/˚C |
| **Nominal operating cell temperature NOCT** | 45 ˚C |
| **Module Efficiency %** | 21.1 % |

The DC heating element immersed in the water tank operates at a power of 1500 W with a DC voltage of 48 V. The purpose of using it is to eliminate electrical conversion losses, as shown in Figure 2.


Figure 2 DC Heating Element

The water tank with a capacity of 120 liters that the DC heating element is immersed in. It works as a solar water heater. Hot water is kept and stored in a hot water tank. Because of the thermosiphon action, the water temperature rises from the bottom to the top of the tank, with the hottest water at the top[34], as it is a heat insulator that maintains the water temperature for the longest possible period.

## 3.3. Data Acquisition System

On 3 January 2024, the data recording and storage system used voltage (SEN32 REV1.1 AC/DC), current (ACS758), flow rate (Flow meter YF-S201), and temperature (MAX6675) sensors, a system was able to record and store data of voltage, current, flow rate, ambient temperature, hot water temperature inside the tank, the water temperature coming to the tank, and water temperature coming out of the water faucet that was produced by the solar panel system. An Arduino Uno is used for this purpose, and data is recorded every 5 minutes starting at sunrise and ending at sunset.
A solar power meter (TES 1333) was used to acquire the solar radiation data, which was recorded every 5 minutes. Figure 3 shown a schematic diagram for the DPVWH with the data acquisition system.

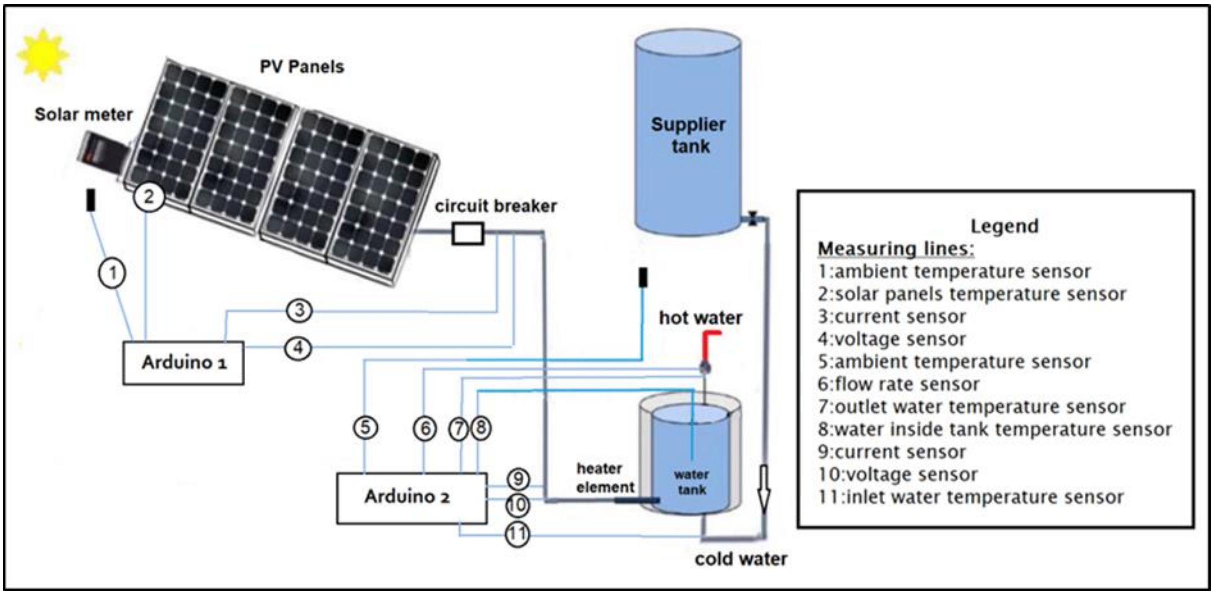


Figure 3 A DPVWH schematic diagram

# 4. RESULTS AND DISCUSSION

The performance of the photovoltaic solar heater was examined and evaluated experimentally by monitoring and recording the following parameters of the system:

### 4.1. Solar Radiation

Solar radiation data was recorded, which was clear and sunny. Its value begins to rise from the beginning of sunrise at seven o'clock in the morning until midday, reaching a maximum and then decreasing until sunset at five o'clock in the evening. There is some variation in the value of solar radiation during the day, which is due to the passage of some clouds in the measurement area. At 1:10 PM, the solar radiation value reached its maximum of 556 $W/m^2$. As shown in Figure 4.

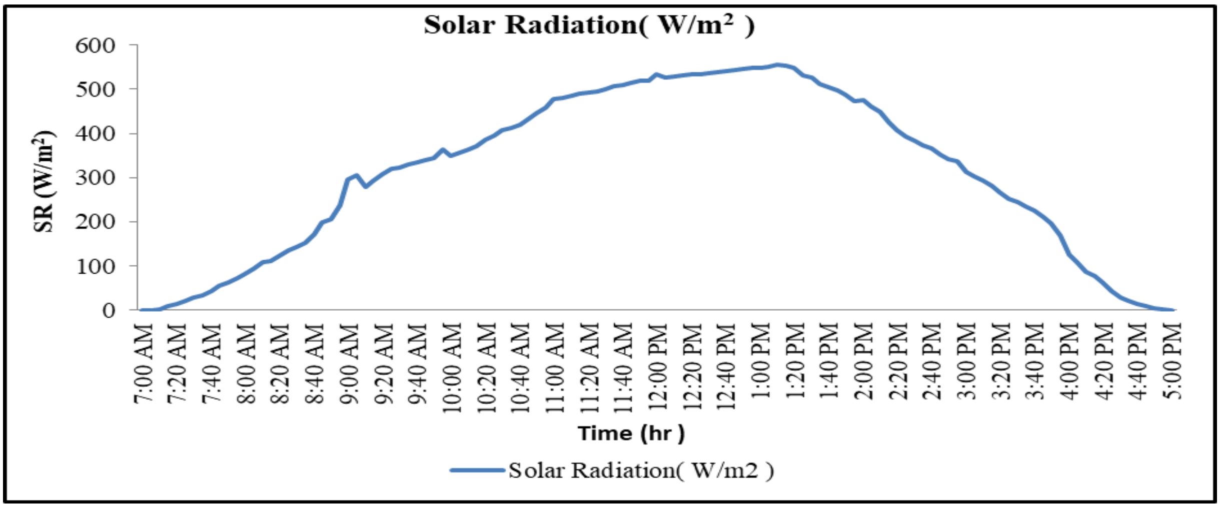


Figure 4 Solar Radiation vs. Time

### 4.2. Ambient and Panels Temperature

The temperature sensors took the day's ambient temperatures at two different locations: next to the PV panels and next to the heater. This allowed the temperature sensors to measure the difference between the two temperatures and how they related to the surface temperature of the PV panels. Figure 5 depicts regular temperatures that rise with the length of the day, however, in these conditions, hot water is necessary for some household tasks like cooking and bathing. Because of the clear weather and high levels of solar radiation, a gradual temperature rise is seen until midday. Due to the PV panel's direct sunlight exposure and the heater's location in the shade, the ambient temperature near the panels was noticeably higher than the ambient temperature near the heater. However, the maximum PV panel's surface temperature was recorded at 28.25 °C, It was somewhat higher due to their effect from the ambient temperature. The measured ambient temperatures on this day seemed to be within the range of 9 to 25.50 ˚C, near both the heater and the PV panels. The maximum ambient temperature near both the heater and the PV panels were 21.75 ˚C at 1:10 p.m. and 25.50 ˚C at 12:30 p.m., respectively.

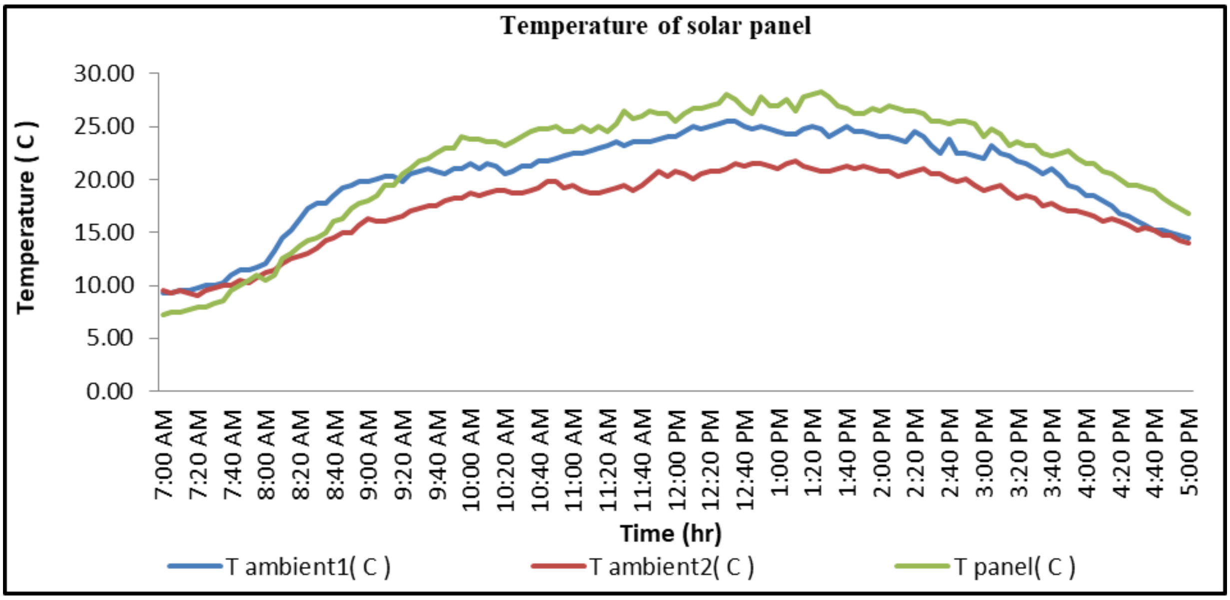


Figure 5 Temperature vs. Time

## 4.3. Water Temperature of The Photovoltaic Solar Heater

As shown in Figure 6, the photovoltaic solar heater was turned on from 7:00 a.m. until 10:20 a.m. The water temperature inside the tank reached 40 ˚C, a temperature that is appropriate for residential usage. The temperature of the water inside the tank is measured near the heating element, so it has the highest temperature gradient, while the temperature of the water outside is measured at the water pipe exiting the heater to know the temperature of the water used when needed. Therefore, the temperature gradient is then different from the temperature of the water inside the tank, and also lower than it. The hot water was used at various times as the house needed to test the DPVWH. The process for varying the PV solar heater's water temperature while it is in use with a flow rate of 2 L/m is shown in Figure 6. Despite the water being used multiple times during the day, the temperature inside the tank reached its highest value, which was 83.50 °C at 2:10 p.m. There were about 131 liters of water that were utilized. It is a suitable consumption for a house of three people.

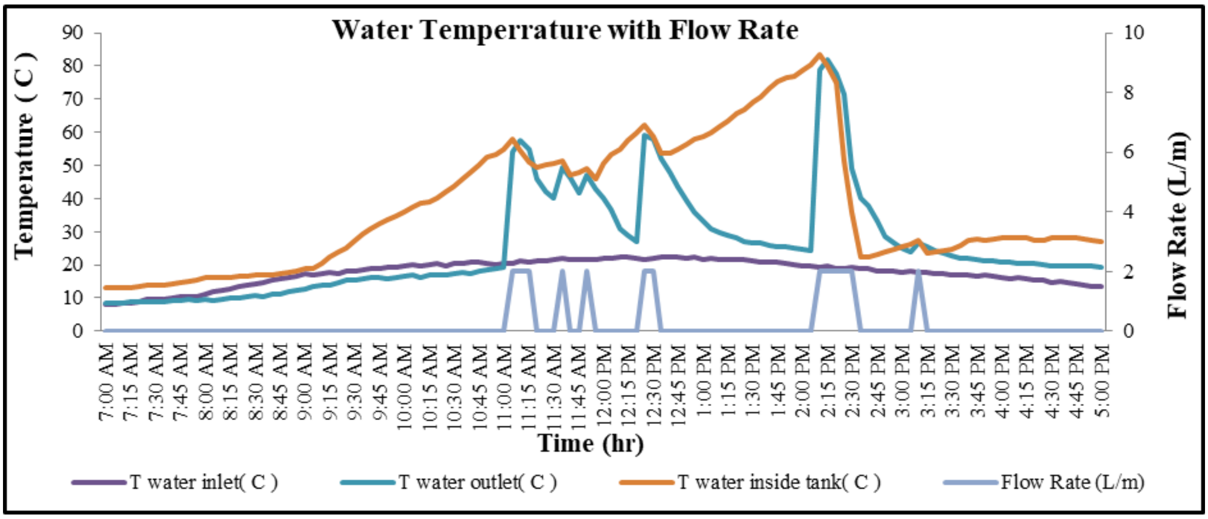


Figure 6 Water Temperature with Flow Rate vs. time

## 4.4. Power and resistance of the photovoltaic solar heater

The relationship between solar radiation power and photovoltaic panel power over time is shown in Figure 7. At 1:10 p.m., the solar radiation power was calculated from Equation 1 and reached its maximum value of 5861 W. At 11:20 a.m., the PV power generated was calculated from Equation 2 and reached its greatest value of 1240 W. From 9:35 am to 1:55 p.m., it was mostly steady. The power values that arrived at the DC heating element were very close to the power generated by PV panels due to the use of DC connecting wires. Its highest value was 1188W. According to the specifications of the heating element used with a capacity of 1500W, there are losses in its power of about 312W. The resistance value of the heating element was calculated from Equation 3 and was 1.6 ohm.

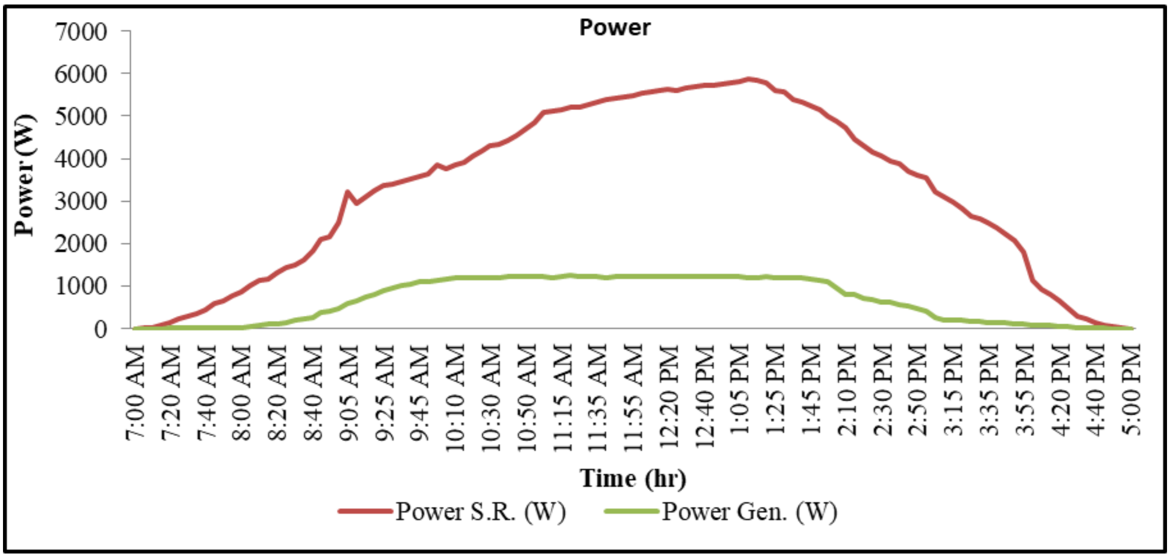


Figure 7 Power of Solar Radiation with Power generated vs. Time

## 5. THE EFFICIENCY ASSESSMENT AND COST AND PAYBACK PERIOD

The efficiency of the DPVWH system is evaluated by determining the electrical efficiency of the photovoltaic model, where the output energy represents $P_{max}$ and the input energy represents the input power at the same time, which is at 11:20 am, through equation (4):
peak hours of the sun: 6 h/day
Solar radiation is 3.2 kWh/m$^2$/day

Converting solar radiation into $\frac{W}{m^2}$, $\frac{3.2\times10^3 \text{Wh/m2/day}}{6\text{ h/day}} = 534.46\frac{W}{m^2}$

$$\eta_{PV} = \frac{P_{max}}{G_T * n * A_{PV}} = \frac{1240}{534.46 \times 4 \times 2.6} = 22.3\%$$

It is considered a suitable value according to the specifications of the PV panels.

The time needed (in years) to recoup the initial investment is known as the payback period. It is a comparison of the cost of a PV solar water heater used in Wasit and the cost of heating water using electricity. The cost of a DPVWH made in Wasit is \$1350 with 10.54 m$^2$ and 120 L of tank capacity. This solar water heating system is enough per day for a family of three members. The average cost of electricity in the world is \$0.15 per kWh. By using equation 7:

$$Q_{load} = m_w \times C_{pW} \times (T_{hot} - T_{cold}) = 131\times4.18\times(59.25-21.75) = 20534.25\text{kJ/day} = 5.7\text{kWh/day}$$

The above data is used to calculate the annual saving cost by utilizing equation 6:

Annual saving = 182 × CE × $Q_{load}$ = 182×0.15×5.7 = \$155.61
And by using equation 5:

$$Payback\ period = \frac{\$1350}{\$155.61} = 8.6\ years$$

The payback period of 8.6 years is low. This is due to the design and high efficiency of the system, as the remainder of the system's operational lifetime is profit.

## 6. CONCLUSIONS

This study presents an analysis of the performance of the DPVWH system. It provides comprehensive analysis by experimenting with the system on a clear, sunny day. By taking into account the components and specifications of photovoltaic panels, as is the case with the weather. The appropriate value of the generated power from PV panels is an important point in determining performance. It depends entirely on the value of the DC voltage and current, the method of connecting the panels, their number, and solar radiation. Its value increases with increasing solar radiation. The highest water temperature recorded inside the PV heater tank was 83.50 °C. 131 liters of water were used as needed for a family of three people at a flow rate of 2 L/m. The highest values of the solar radiation power, the PV power generated, and the power delivered to the heating element were 5861 W, 1240W, and 1188W, respectively. According to the specifications of the heating element used with a capacity of 1500W, there are losses in its power of about 312W. The electrical efficiency of the system was calculated and it was 22.3%. The payback period to recover the system's initial investment was 8.6 years, which is an appropriate value that represents a profit for the remainder of the system's operational life. This system can be considered an alternative to STWH to overcome the problems of impurities in the water used for domestic purposes, which reduce the efficiency of STWH systems, and to overcome heat losses when transporting water through pipes. From these results, it can be recommended to use DPVWH systems in cold weather conditions because it has proven its economic feasibility for such applications in Iraqi conditions and its investment effectiveness in residential water heating applications and using the system throughout the year, as its use is not limited to heating water in the winter as in STWHs. In addition to the simplicity of the system, it solves many problems of thermal losses in transferring energy from the generation source to the electrical and thermal load. These systems are less susceptible to damage compared to STWHs, which are technologies that operate during hours of sunlight.

## 7. FUTURE WORK

1. By raising the solar radiation on the second (back) side of the photovoltaic panels, the impact of the Albedo on the system's performance will be evaluated.
2. The system can be utilized all year round, serving as a cooling system in the summer and a heating system in the winter.
3. The validity of the experimental data can be confirmed by conducting a simulation model with the TRNSYS software.

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