Journal of Engineering
journal homepage: www.joe.uobaghdad.edu.iq
Number 8 Volume 26 August 2020

Mechanical and Energy Engineering

Experimental Evaluation of Evaporative Cooling for Enhancing Photovoltaic Panels Efficiency Using Underground Water

Arwa Mahmood Kadhim
Researcher
College of Engineering, University of Baghdad
E-mail: energy81.amk@gmail.com

Issam Mohamed Ali Aljubury*
Assistant Professor
College of Engineering, University of Baghdad
E-mail: drissam@uobaghdad.edu.iq

ABSTRACT

This paper presents an experimental study of cooling photovoltaic (PV) panels using evaporative cooling. Underground (geothermal energy) water used to extract heat from it during cooling and cleaning of PV panels. An experimental test rig was constructed and tested under hot and dusty climate conditions in Baghdad. An active cooling system was used with auxiliary an underground water tank to provide cold water as a coolant over both PV surfaces to reduce its temperature. The cellulose pad has been arranged on the back surface and sprays cooling on the front side. Two identical PV panels modules used: without cooling and evaporative water cooling. The experiments are comprised of four cases: Case (I): backside cooling, Case (II): front and back cooling (pump supply water every 35 minutes), Case (III): cooling both sides using Arduino controller. Water cooling pump operation depending on the panel temperatures (temperature sensors were installed on the front of the panel), Case (IV): Repeating case III with different water flow rates. Experimental results showed that the average reduction in module temperatures was 4, 8,12.2 and 12.6 ºC respectively by Case (I), (II), (III) and (IV) with respect to a non-cooling module. Using evaporative water cooling achieved a total improvement of 1.74%, 2.8%, 15.8%, and 16% in the conversion efficiency of the panel by the Case (I), (II), (III) and (IV) respectively when compared to a non-cooling module.

Keywords: Solar Photovoltaic Cooling; Evaporative Cooling; Geothermal Energy; Solar Photovoltaic Cleaning.

*Corresponding author
Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2020.08.02

Article received: 13/12/2019
Article accepted:6/4/2020
Article published:1/8/2020

التقييم التجريبي للتبريد التبخيري لتعزيز كفاءة الألواح الضوئية باستخدام المياه الجوفية

اروى محمود كاظم
باحث
جامعة بغداد,كلية الهندسة

عصام محمد علي
أستاذ مساعد
جامعة بغداد,كلية الهندسة

الخلاصة

تقدم هذه الورقة دراسة تجريبية لتبريد الألواح الكهروضوئية باستخدام التبريد التبخيري. استخدمت المياه الجوفية (الطاقة الحرارية الأرضية) في استخلاص الحرارة من الألواح الكهروضوئية أثناء التبريد وتنظيفها. تم بناء منظومة اختبار تجريبية واختبارها في ظل ظروف المناخ الحار والغبار في بغداد.استخدم نظام تبريد نشط مع خزان مياه تحت الأرض لتوفير الماء البارد لتبريد كلا السطوح الكهروضوئية وتقليل درجة حرارتها. تم ترتيب وسادة السليلوز على السطح الخلفي وتبريد الرش على الجانب الأمامي. اثنين من وحدات الألواح الكهروضوئية المتطابقة استخدمت: بدون تبريد وتبريد بالماء التبخيري. تتضمن التجارب أربع حالات: الحالة (I): التبريد الخلفي ، الحالة (II): تبريد أمامي وخلفي (المضخة تزود الماء كل 35 دقيقة) ، الحالة (III): تبريد كلا الجانبين باستخدام جهاز التحكم الاردوينو الذي يشغيل مضخة مياه التبريد حسب درجة حرارة اللوحة (تم تثبيت أجهزة استشعار درجة الحرارة في مقدمة اللوحة) ، الحالة (IV): حالة التكرار III بمعدلات تدفق مياه مختلفة. أظهرت النتائج التجريبية أن متوسط التخفيض في درجات حرارة اللوحة كان 4 و 8و12.2 و 12.6 درجة مئوية على التوالي حسب الحالة (I) و (II) و (III) و (IV) بالمقارنة مع اللوحة بدون تبريد. حقق استخدام التبريد بالماء التبخيري تحسنًا إجماليًا قدره 1.74٪ و 2.8٪ و 15.8٪ و 16٪ في كفاءة تحويل اللوحة بواسطة Case (I) و (II) و (III) و (IV) على التوالي بالمقارنة مع اللوحة بدون تبريد.

الكلمات الرئيسية: تبريد الالواح الكهروضوئية , التبريد التبخيري, الطاقة الحرارية الأرضية, تنظيف الخلايا الشمسية.

1.INTRODUCTION

Energy consumption is one of the key factors that contribute directly to enhancing the standards of human living. Therefore, tireless efforts have been attempted to achieve this goal. Many energy forms are available on our earth, such as geothermal, solar, hydro, wind, tidal, oil, natural gases, coal, and other fossil fuels. Fossil fuels are the dominant source to meet energy requirements. However, the consumption of fossil fuels has increased dramatically, leading to depleting the fossil fuel reserves and climate change severe impact. Therefore, natural and renewable energy resources are a viable way to provide clean energy. The sun is the main energy source in the world. Solar panels are one of the promising methods to utilize this energy. In the last two decades, the increase in PV cell efficiency and the relative reduction in price mainly contributed to increasing the installation percentage of solar photovoltaic (PV) panel systems. French scientist Edmond Becquerel discovered the photovoltaic effect in 1839. This effect firstly utilized by Charles Fritts to make the first solar cell with an efficiency of about (1-2)% in 1883 (**Satpute and Rajan, 2018)**. Nowadays, different types of solar cells are available. The common type is silicon semiconductors with an efficiency falls between 14%-17% **(Ahmad et al., 2018).** Practically, PV cell converts some fraction of solar irradiance (15%-20%) into electrical power. At the same time, the remainder is released by reflection (re-radiation or convection) or conversion into heat, leading to an increase in the temperature of PV cells more than the standard test conditions (STC). The STC is 1000 W/m^2 and 25 °C **(Schiro et al., 2017).**

The temperature of the PV cell is the main parameter used to assess its performance. The reduction in efficiency can be attributed to the rise in PV cell temperature more than the standard test conditions. Overheating may also cause damage to adhesive seals, delamination, and non-homogeneous temperatures (hot spots). Practically, the installation of solar PV panels in tropical and hot climate countries requires the use of cooling techniques to keep the temperature of the PV panel close to the standard condition (25°C) **(Fatoni et al., 2019).**

The efficiency of PV panels is based on the standard test temperature of 25ºC. However, the high solar incident will increase the temperature of the PV panels, and that will decrease the efficiency of the PV. Every increase in temperature by 1°C corresponds to the decrease in efficiency by 0.5% **(Ahmad et al., 2018).** Moreover, the high temperature of a solar cell for a long time also shortens its service life. Therefore, to achieve both higher PV efficiency and higher electrical output, the PV must be cooled by removing the heat in some way. Therefore, to cool the cells in the PV system, a photovoltaic panel is integrated with a cooling system. Cooling of the PV improves efficiency, and heat can be used in space heating or for drying systems and moreover, it is less costly than two separate units.

Cooling the panels using a suitable cooling method helps to tackle this problem partially. This would help to improve the efficiency and power output. Many cooling techniques were proposed to cool the PV panels and enhance their electrical performance. This includes active and passive cooling with different cooling media **(Nižetić et al., 2016).**

The commonly used cooling methods are air and water methods. Air cooling requires less energy than water cooling, but its cooling capacity is mediocre. Conversely, water has better cooling capability than air, but its equipment costs are usually higher than air cooling **(Yang et al., 2019).**

The spray water cooling technique has proved its ability to improve PV panel electrical power output (**Nižetić et al., 2016).** Other benefits reported with this technique, are when used on the cell front surface, remove dust and dirt from the cell and reduce reflected radiation by forming a thin layer of water, which in turn helps to improve cell efficiency **(Raval et al., 2014).**

The evaporative PV panel water cooling technique is using a cellulose pad, which saturated by water through a perforated tube. This type of cooling system dissipates heat due to evaporation of water from the back surface of the PV panel. This method is easy to implement, quiet with low pumping capacity, availability of components in the domestic market, and low cost and maintenance (**IA. Hasan and S. R. Fafraj, 2017**).

Dust deposition is one of the challenges facing the installation of solar PV systems under tropical weather conditions. The loss of performance due to the accumulation of dust depends on the accumulated dust particles, chemical composition, size, and density **(Said et al., 2018).**

The variation in the accumulation of dust largely depends on other weather conditions such as temperature, rainfall, wind, and any other climatic events that occur during the experiment. The orientation and tilt angle of the PV surface affects the deposition of dust particles, i.e., increasing the tilt angle generally promotes the removal of dust due to gravity **(Hachicha et al., 2019).**

It was found that the gradual accumulation of dust over a period of eight weeks decreased the spectral transmissivity of the glass from 91% to 46.09%, and reduced its electrical output by 44.16% and COP by 8.53% under the conditions tested. the working temperature of the cell decreases for a given atmospheric environment, while the glazing temperature increases with the accumulation of dust **(Vaishak and Bhale, 2019).**

2. A BRIEF OVERVIEW OF THE PREVIOUS PV COOLING RESEARCH FINDINGS

(**Abdelrahman et al., 2013**) developed a cooling system to improve the efficiency of the photovoltaic PV panels. Three types of cooling systems were used in the experimental work: film water, direct contact backwater, and combining film-back cooling. The distribution of the panel surface temperatures was obtained by using the infrared camera. Experimental results showed an increase of 22%, 29.8%, and 35% in the daily output power was noted in the mentioned three cooling methods when compared to the non-cooling module.

An attempt was made by (**Moharram et al., 2013)** to reduce the amount of water and electrical energy required for the cooling of the solar panels, especially in hottest regions. A mathematical model was used to determine the heating rate of the PV panels and at what maximum allowable temperature 45°C to start cooling, as well as a cooling rate model to define the duration of cooling to reach the normal operating temperature (35 ºC). The two models were validated experimentally and showed that the maximum PV panel yield was obtained at the maximum allowable temperature.

The increase of PV cell operating temperature during absorption of solar radiation is an unfavorable condition as it will cause a reduction in the electrical efficiency of the PV. In order to avoid that, the cooling of the PV cell is required. The cooling technique was investigated using an absorption sponge fixed on the backside of the photovoltaic panel by (**Musthafa, 2015)**. The experimental results from this novel technique found a direct relationship between efficiency and temperature. The solar cell had an efficiency of 8–9% without cooling, but when it operated under the cooling system, a 12% increase in the efficiency of solar cells was achieved when the temperature dropped by 40°C.

In combination with cotton wicks, a passive thermal regulation technique is developed **(Chandrasekar and Senthilkumar, 2015) t**o regulate the PV module temperature during its operation. The thermal and electrical output of the thermally regulated solar PV module was also compared with the results of the non-cooling solar PV module. The temperature of the PV module had been reduced by 12%, while the electrical output was increased by 14% by the effect of this cooling system. The basic energy balance formula applicable to the PV module was used to determine the coefficient of thermal loss that was found to increase in moist cotton wicks due to the finite effect of the heat spreader and evaporative cooling.

The PV module operating temperature has a significant effect on the PV module performance, the output of four modules was investigated and compared: mono-crystalline silicon, poly-crystalline silicon, amorphous silicon, and copper indium gallium di-selenide under Baghdad's climate conditions **(E. Hashim, 2016).** The experimental results showed that the temperature increase led to a slight increase in the short circuit current and a greater decrease in the open-circuit voltage, leading to a decrease in the output power of the modules. Amorphous silicon was suitable for high operating temperatures but had the lowest efficiency of conversion among the four modules.

One of the problems with the use of the solar PV system in Iraq is the impact of dust deposition on the surface of PV panels. This problem was investigated by (**Hashim, 2016)** during June, July, August, October, and September with fixed solar PV panel and different inclination (15,33,45,60)º. Results showed that the highest tilt angle (60º) resulted in the highest average performance of the panel, which was 7.4%, 6.7%, 8.0%, 8.1%, and 8.4% for the corresponding months; June, July, August, October, and September.

An alternative technique was proposed and studied the application of water spray over panel surfaces (both sides of the PV panel being cooled simultaneously) to investigate the total water spray cooling effect on the PV panel performance in circumstances of peak solar irradiation under a Mediterranean climate **(Nižetić et al., 2016).** Results indicated that this cooling technique achieved an increase in electric power output of about 16.3% (effective 7.7%) and in PV panel electrical efficiency of about 14.1% (effective 5.9%) as well as reducing the average panel temperature by about 30°C. Furthermore, another advantage of this new cooling technique is its self-cleaning effect, which made it more economical.

Two types of cooling, continuous cooling, and cooling every one hour were conducted, and the results from these two techniques were compared with those obtained from a non-cooling

photovoltaic panel system (**Sukarno et al., 2017)**. The output power of the continuous cooling panel, cooling every one-hour panel, and without cooling panel was 68.8 W, 65.11 W, and 59.06 W, respectively, and the efficiency was 16.7%, 14.4%, and 13%. In conclusion, the output power of the continuous cooling panel was higher than that without cooling.
A novel method to cool the photovoltaic PV panel by a cellulose pad arrangement was carried out **(IA. Hasan, S. R. Fafraj, 2017).** The cellulose pad was saturated with water and placed at the back surface of the panel. This cooling technique caused a reduction in the average panel temperature of about 10.1°C and led to an increase in panel efficiency of about 20.7%. The low costs of the cellulose pad gave additional economic features to that method.
(Haidar et al., 2018) experimentally investigated the effect of evaporative cooling of solar photovoltaic (PV) panel efficiency. The PV panel back surface was wetted and exposed to surrounding. Water tank supplied by gravity to the back surface of the PV. Results show that temperature reduction more than 20 °C in the PV panel and around 14% increment in electrical efficiency were achieved compared with an uncooled PV panel.
An alternative method to solve the problem of accumulated dust and dirt on the panels used an automatic cleaning system (spray mechanism), which cleaned the PV panel automatically using a timer **(B, Manju, et al., 2018)**.
An inverse proportion between temperature and panel power was noticed (**Zilli et al., 2018)**, the effects of temperature and the solar radiation on the PV panel power was further examined using simulation by PSIM and MATLAB programs.
A cooling system using shallow-geothermal energy to enhance the photovoltaic PV panel efficiency was investigated **(Yang et al., 2019).** The experiments involved three stages: Panel operated without a cooling system, the cooling system used to cool the panel, but without a UBHE, the cooling system was operated with a UBHE. Experimental results and mathematical models proved that the system with a UBHE could cool the PV panel more effectively than the system without a UBHE. Consequently, this improved the panel conversion efficiency by 14.3% under 1000 W/m^2 of solar radiation and when ten panels were used.
The current study will investigate the utilization of active spray and evaporative cooling techniques to control the temperature rise of PV modules that occur due to the absorption of solar irradiance. The method involves incorporating a spray nozzle and cellulose pad to the back of the module and allowing a thin film of water to evaporate, and thus reducing the module temperature.

3. THE EXPERIMENTAL SETUP

In this research, two photovoltaic PV panels were used, one of them was cooled by evaporative cooling techniques, and the other was left without cooling for comparison (as a standard case), **Table 1.** The Photovoltaic PV Panel Specifications show the photovoltaic PV panels specifications at standard test conditions (T=25°C, R=1000 W/m^{2,} and AM=1.5).

Table 1. The Photovoltaic PV Panel Specifications.

Parameter	Value
P_m	50W
I_m	2.9A
V_m	17.2V
I_{sc}	3.25A
V_{oc}	21.8V
Weight	6Kg
Dimension	(845×545×35) mm

The two identical PV panels where: First is the panel without cooling, and second is the panel with an evaporative water technique. The two PV panels were installed on an inclined supporting structure, which allows water runoff through gravitational force.

A cellulose pad has been arranged on the back surface of the PV panel, which was saturated with water from the small reservoir by a small water pump through a perforated pipe in the top of the back surface of the panel. A small reservoir was filled with cold water from the underground tank by a submersible water pump (50LPM, (5-13) m high, and 0.4kW), four water nozzles were installed on the front surface of PV panel. A water flow sensor (30LPM) was used to measure the water flow rate and six temperature sensors (DS18B20) on the PV panel to measure the temperature. Five of them on the back surface and one on the front surface, as shown in

Figure 1. Outdoor Experimental Setup.

Two types of small water pumps were used. (I) 1000LPH, 1.8m, and 25W and (II) 2000LPH, 2.5m, and 70W for pumping water from the small reservoir to cool the PV panel. A temperature sensor placed inside the small reservoir to measure the water temperature inside the reservoir. Glass wool was used to insulate the small reservoir to keep the water inside it cold. The water flow in a closed circuit, the drain was collected and sent back to the underground tank by gravity, **Fig.2** and **Fig.3**.

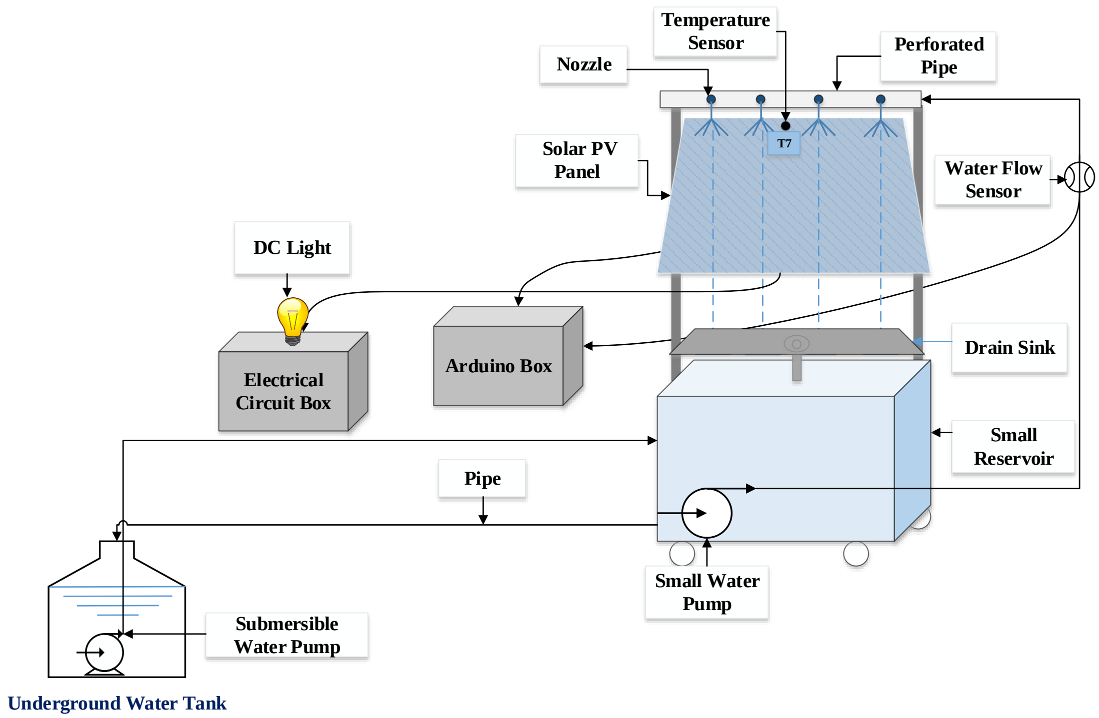


Figure 2. Front View of the Cooled PV Panel.

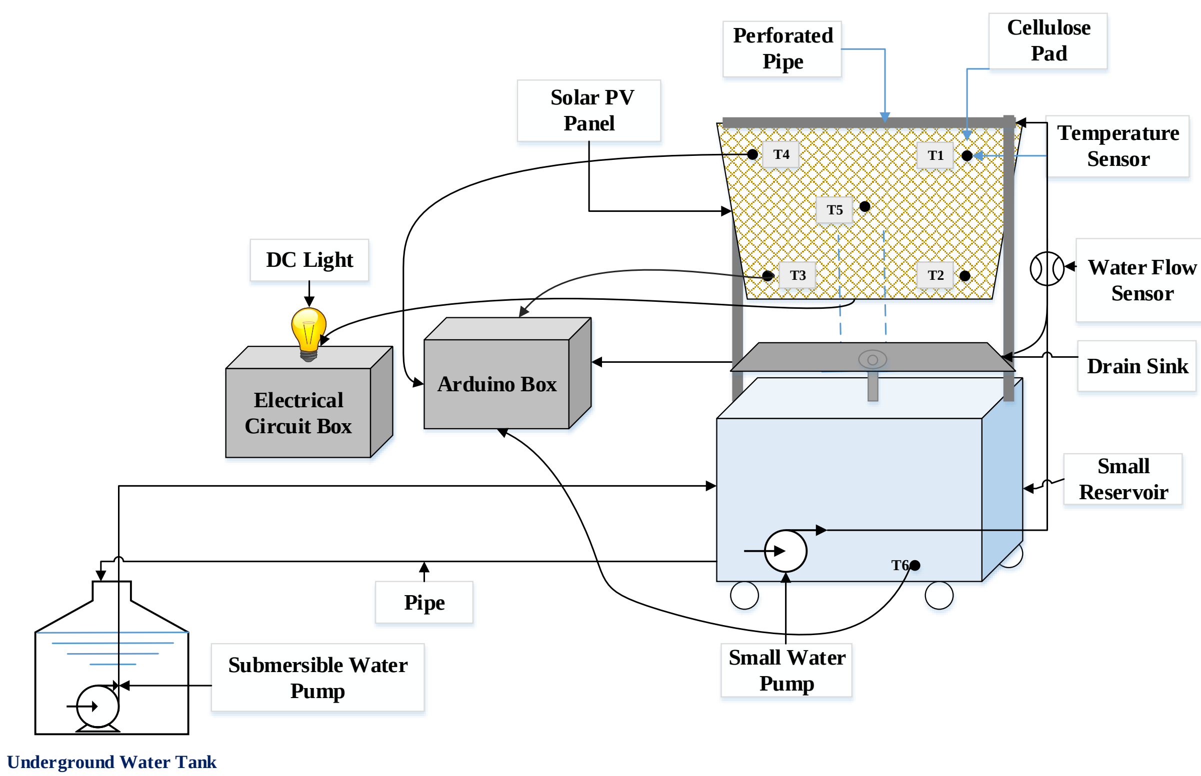


Figure 3. Back View of the Cooled PV Panel.

The readings were recorded using the Arduino system (Arduino Mega 2560) for five days in each of May, June, July, and August in 2019, and as follows:

- **The first day**: The readings were recorded without using the cooling technique.
- **Second day**: Case (I), the readings were recorded using a cooling technique on the back surface of the PV panel only with a maximum water flow rate. The small water pump (I), with the use of a special program, was switched on for 2 minutes every 35 minutes.
- **Third day**: Case (II), repeat the procedure of the second day with cooling technique and maximum water flow rate divided onto the front and back sides of the PV panel.
- **Fourth day:** Case (III), where the small water pump (I) switched ON depending on the reading of temperature sensors on the front surfaces of the PV panels, it pumped the maximum water flow when the temperature sensor reading exceeds 45 °C and vice versa.
- **Fifth day:** Case (IV); the procedure of the fourth day was repeated with a minimum water flow rate using a small water pump (II).

In all cases, in this paper, the cooling water was supplied from a buried underground tank, which helped to keep the temperature of the cooling water at approximately equal 18.5 ºC lower than the daily ambient temperature on average.

4. UNCERTAINTIES IN EXPERIMENTAL DATA

The accuracy of the instrumentation and the human error readings caused uncertainties for any parameter in the measured data. Error! Reference source not found. described the uncertainty values of different dependent and independent parameters.

Table 2. Uncertainty of the Operating Parameters.

Parameters	Range	Resolution or Sensitivity	Accuracy
DS18B20 Temperature sensor	-55 to 125°C (-67°F to +257°F)	/	±0.5°C
Voltage Sensor	DC0-25 V	0.00489 V	/
Acs 712 DC Current Sensor 5A	-5A~ 5A	180mV/A ~190mV/A, Typical: 185mV/A.	
Digital Relative Humidity and Temperature Sensor	humidity 0-100%RH; temperature -40~80Celsius	humidity: 0.1%RH; temperature 0.1Celsius	humidity +-2%RH (Max +-5%RH); temperature +-0.5Celsius.
Water Flow Sensor	1～30 L/min.	/	/
Wind Speed Sensor	0.5m/s to 50m/s	0.1m/s	Worst case 1 meter/s
solar power meter	2000 W/m^2	0.1 W/ m^2	The greater of ±10 W/ m^2

5. RESULTS AND DISCUSSIONS

Environmental parameters strongly affect the operating performance of the PV panel. Also, solar radiation and ambient temperature affect the efficiency of PV panels as well as their operating temperature.

Fig.4 shows the average global radiation for the months: May, June, July, and August in 2019. Generally, the range of solar radiation is (600-1000) W/m^2 in the high-level irradiation period through these months. The maximum value of the global radiation recorded through the four months was 1081 W/m^2 at (12:00 am) on the 17th day of August 2019, whereas the highest average global radiation was 1045.25 W/m^2 at (12:00 am). It is clear that there is a direct relation between electrical power and the efficiency of the module with solar radiation. The average electrical power of the uncooled panel was 36 W, and the average efficiency was 7.47% during the recording of the measurements at solar noon (12:00 pm to 2:00 pm).

$$P_m = I_m * V_m \quad (1)$$

$$E = (P_m / (A * R)) *100\% \quad (2)$$

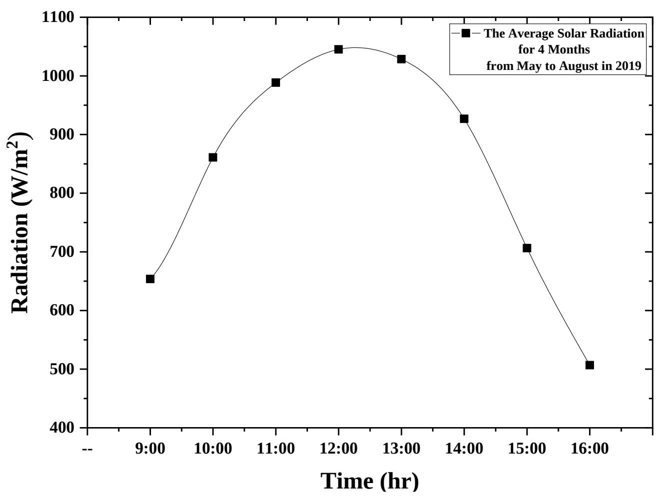


Figure 4. The Average Solar Radiation of the 4 Months from May to August in 2019.

The average ambient temperature of the air at the same months, from (9:00 am) to (4:00 pm) are shown in **Fig.5.** Although the maximum temperature occurs at solar noon depending on the radiation, it was noticed that the highest average temperature (56.4ºC) observed at 2 pm. This is the result of surrounding materials absorbing radiation during the day and radiating it later, which led to the deviation of the peak to 2 pm.

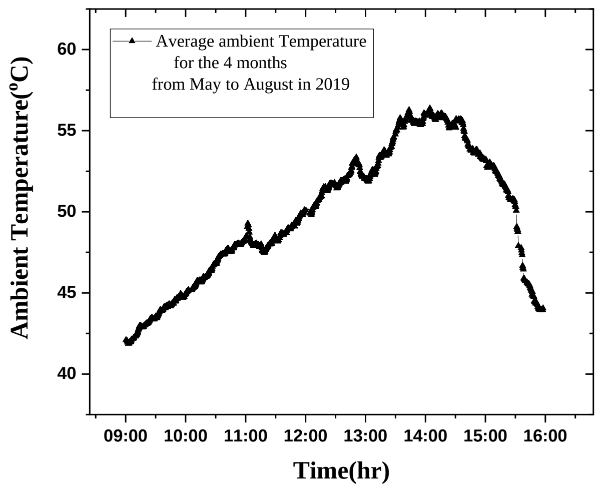


Figure 5. The Average Ambient Temperature for the 4 Months from May to August in 2019.

It is well known that the PV panel is made of semi-conductive materials. This means that a large portion of the absorbed radiation will cause an increase in the PV panel temperature. According to readings on the 2nd day of May, it can be observed that the average temperature of the cooled panel was (61.5 ⁰C) without cooling, i.e., higher than the reference panel (uncooled panel) which was (54 ⁰C) as shown in **Fig.6**. The placing of cellulose pad on the back surface of the PV panel without wetting prevent convective heat transfer from it and therefore causing an increase by about seven ⁰C above the temperature of the uncooled panel.

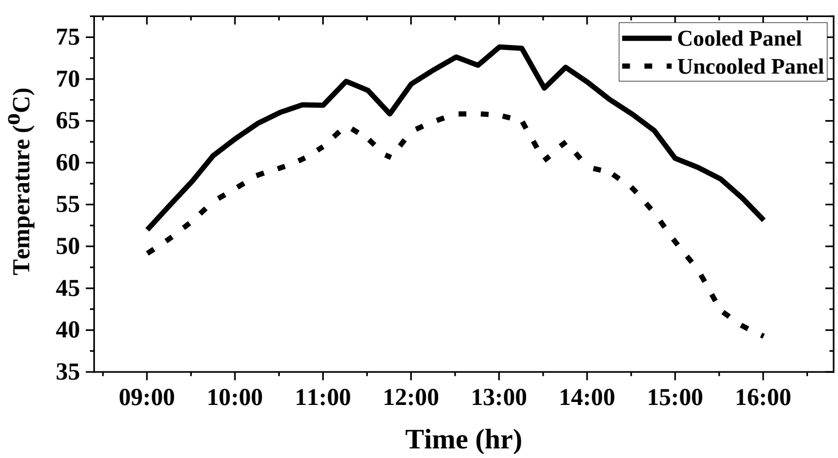


Figure 6.The Temperatures of Photovoltaic (PV) Panels without Cooling on the 2nd day in May in 2019.

Fig.7 shows the temperatures of PV panels without cooling and after removing the cellulose pad from the pack of the cooled panel. It's clear that the temperatures of the two PV panels increased gradually from 9:00 am and reached the maximum temperature of about 57 ºC at 12:15. Also, there was a slight difference due to a number of reasons, including the operational duration of the panels, and the effects of the surrounding.

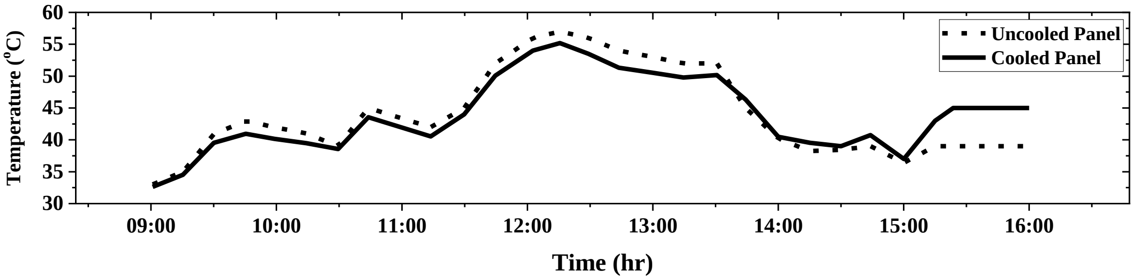
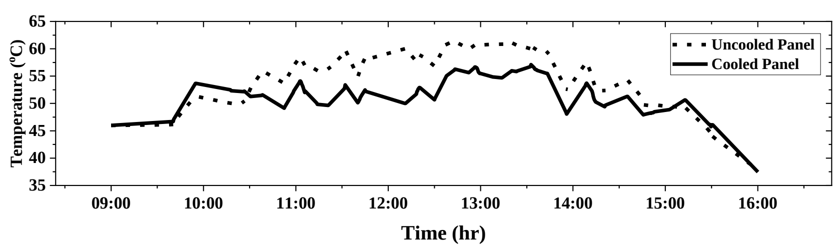


Figure 7. Temperatures of Photovoltaic (PV) Panels Without Cooling Techniques and Without Packaging of the Cooling Panel on the 3rd Day in May in 2019.

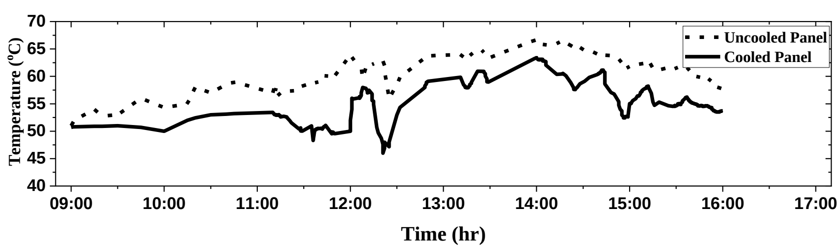
5.1 PV Panels with Cooling Techniques Case (I)

Fig.8 (a, b, c, and d) shows the PV panels temperature of case (I) from May to August. It's clear that the uncooled PV panel has the highest temperature compared with the cooling panel. The maximum uncooled PV panel temperature ranged from (61.3-68.3) ºC through the interval of maximum solar radiation, i.e., from (12:00 to 2:00) pm. The sudden drop in temperatures of the two PV panels shown in **Fig.12** (a and b) at 1:55 pm and at 12:25 pm, respectively, is due to a shadow of a partial cloud. During the measurements, the average wind speed equal to 2.5 m/s. Each temperature curve in the four figures is the result of the average measurements of five temperature sensors on the back surface of the PV panel. The average temperature of the uncooled PV panel was 60.8 ºC. At the same time, the average temperature of the cooled PV panel (with maximum water flow rate 5 LPM) decreased about four ºC compared with the uncooled PV panel. In this case of comparison with the uncooled PV panel, the applied cooling technique improved the power of the PV panel by 1.6% and enhanced its efficiency by 1.7%.

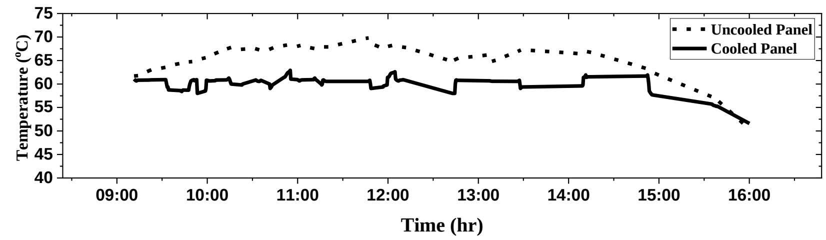
$$E_{improved} = ((E_{withcooling} - E_{withoutcooling}) / E_{withoutcooling}) * 100\% \quad (3)$$



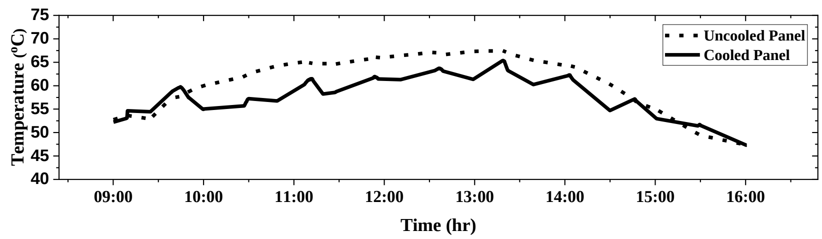
a. Temperatures of PV Panels Case (I) on 8th in May



b. Temperatures of PV Panels Case (I) on 16th in June



c. Temperatures of PV Panels Case (I) on 24th in July

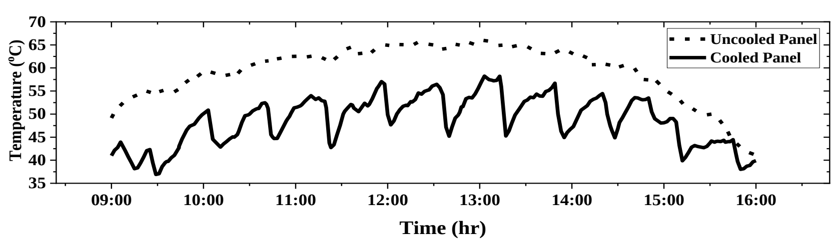


d. Temperatures of PV Panels Case (I) on 17th in August

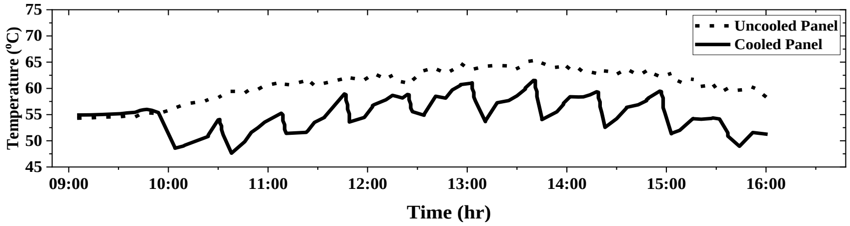
Figure 8. Relationship between the PV panel temperatures during different months for Case (I).

5.2 Photovoltaic (PV) Panels with Cooling Techniques Case (II)

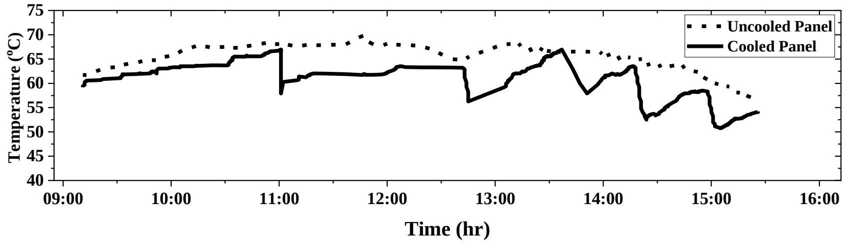
The cooling system was run to take the readings of case (II), with sunny weather through the four months **(**May, June, July, and August**)** as shown in **Fig.9 (a, b, c, and d)** with an average wind speed for about 2.8 m/s. For these months, the maximum temperature of the uncooled PV panel varied from (63.4 ºC to 66.2 ºC) at solar noon. In this case, it is obvious that the temperature fluctuation of the cooled panel is due to Arduino's control of the water pump (I) by means of front water spray cooling. This case showed clearly the effect of cooling and cleaning the PV panels on their performance, with a maximum water flow rate divided into both sides, 5 LPM for cooled panel. In comparison to the average temperature of the uncooled PV panel, which was 63.2 ºC, the cooling of both front and backside of the cooled PV panel reduced its average temperature to 55.2 ºC (about 8 ºC). Throughout this case, the power of cooled PV panel increased by about 2.7% and its conversion efficiency by about 2.8%.



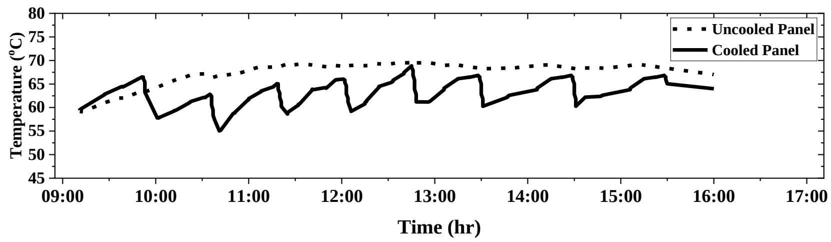
a. Temperatures of PV Panels Case (II) on 14th in May



b. Temperatures of PV Panels Case (II) on 19th in June



c. Temperatures of PV Panels Case (II) on 23th in July



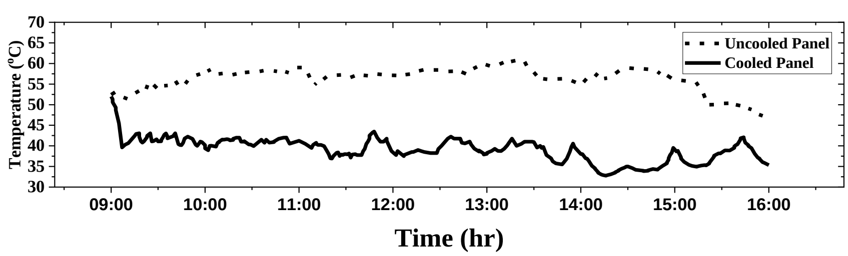
d. Temperatures of PV Panels Case (II) on 19th in August

Figure 9. Relationship between the PV panel temperatures during different months for Case (II).

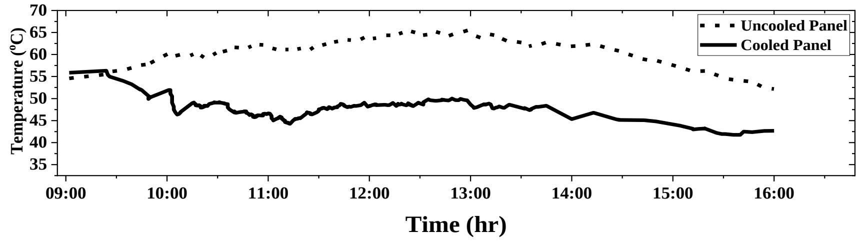
5.3 PV Panels with Cooling Techniques Case (III)

The readings, in this case, were taken during the four months from May to August in 2019 as shown in **Fig.10 (a, b, c, and d)** The maximum temperature of uncooled PV panel ranged from 60.7 ºC to 67.8 ºC at solar noon. This case increased the cooling effect of the cooled PV panel and maintained its back temperature at around 45 ºC.

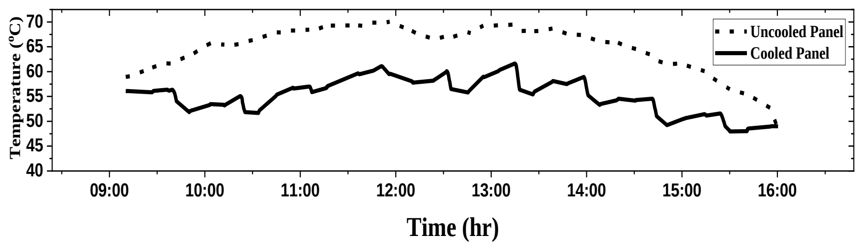
With an average wind speed of about 3.2 m/s, the effect of water cooling on both sides of the PV panel combined with the maximum water flow rate 5 LPM, resulted in a rapid drop in the average temperatures of the cooled PV panel by about 12.2 ºC compared to the average temperature of uncooled PV panel which measured temperature about 64.25ºC. The experimental results from this case show that the power of the cooled PV panel improved by 15.6% and its efficiency by 15.8%.



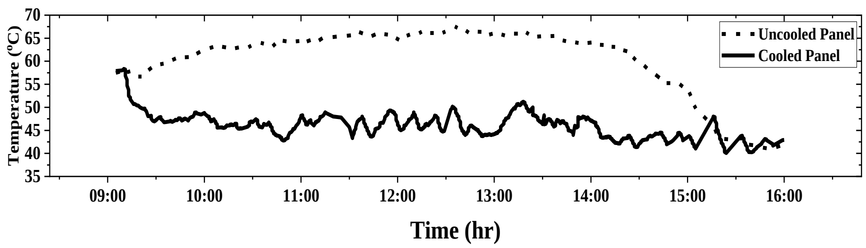
a. Temperatures of PV Panels Case (III) on 27th in May



b. Temperatures of PV Panels Case (III) on 22nd in June



c. Temperatures of PV Panels Case (III) on 25th in July



d. Temperatures of PV Panels Case (III) on 20th in August

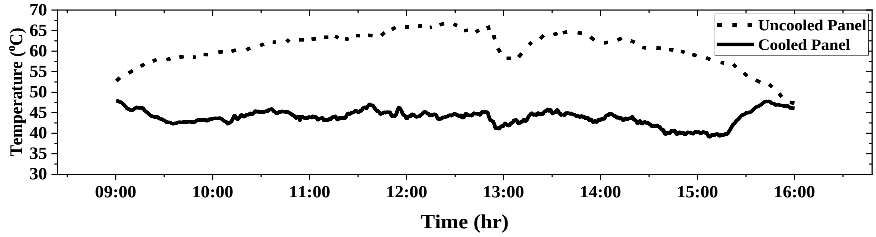
Figure 10. Average Temperatures of Photovoltaic PV Panels Case (III).

5.4 PV Panels with Cooling Techniques Case (IV)

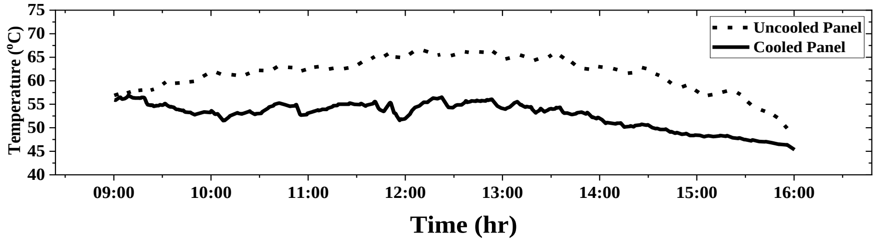
In Case (IV), the system was run in sunny weather and average wind speed of about 3.2 m/s, as shown in **Fig.11 (a, b, c, and d)**. The readings were recorded when the water-cooling technique applied on both sides of the cooled PV panel with the lowest water flow rate 3.5 LPM. The maximum temperature of the uncooled PV panel was ranged from 66.7 ºC to 73 ºC for the months (May, June, July, and August). The results showed that the average temperature of the cooled PV panel B decreased to 48.6 ºC (a reduction of about 12.6 ºC from the average temperature of the uncooled PV panel, which was 61.2 ºC. The conditions used in this case increased the power of the cooled panel and its efficiency by 16%.

In general, case (IV) provided maximum average output power 41.78 W for the cooled PV panel compared with the uncooled PV panel 36 W at solar noon from 12:00 pm to 2:00 pm, among other cases, the performance of PV panels, in this case, illustrated in **Fig. 12-14**.

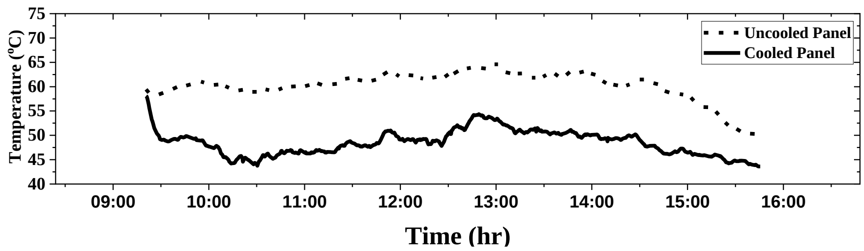
As shown in **Fig.12**, this decreased temperature resulted in an increase in PV power output with a minimum water flow rate of 3.5 LPM. The maximum average output current of cooled and uncooled PV panels was 2.45 A and 2.3 A, respectively, as shown in **Fig.13**, while the maximum average voltage of them was 18 V, and 17 V respectively, as shown in **Fig.14** at solar noon.



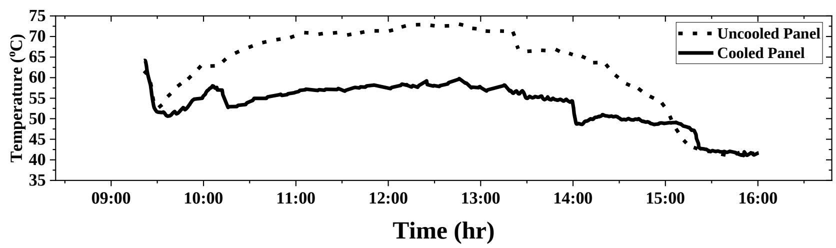
a: Temperatures of Panels Case (IV) on 30th in May



b: Temperatures of Panels Case (IV) on 21st in June



c: Temperatures of Panels Case (IV) on 26th in July



d: Temperatures of Panels Case (IV) on 21st in August

Figure 11. Average Temperatures of Photovoltaic PV Panels Case (IV).

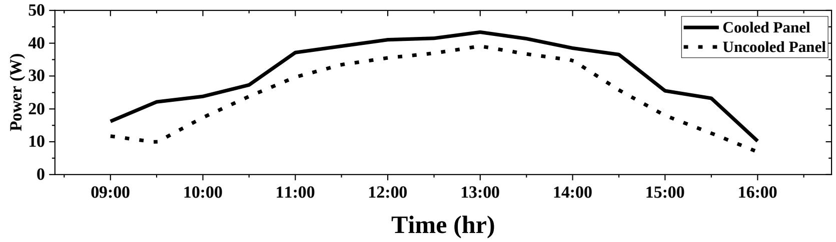


Figure 12. Average Panels Power of Case (IV) for four Months in 2019.

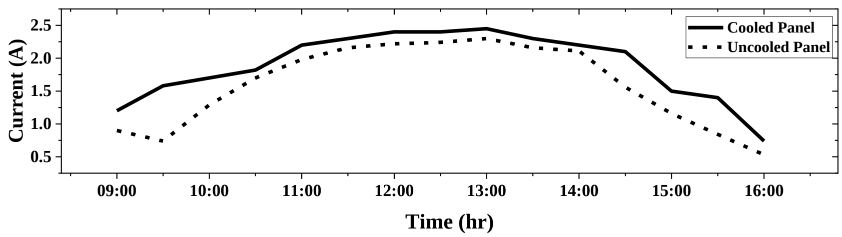


Figure 13. Average Panels Current of Case (IV) for four Months in 2019.

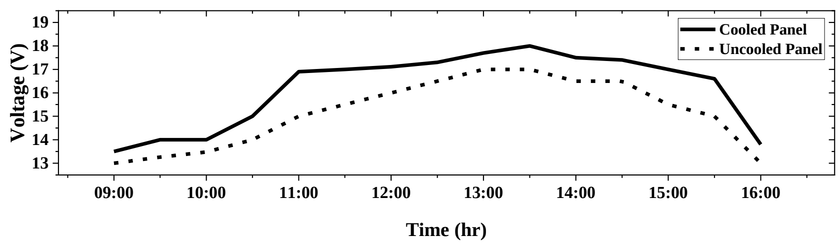


Figure 14. Average Panels Voltage of Case (IV) for four Months in 2019.

The operation of the water pump (II), in this case, depends on the reading of the temperature sensor placed on the front surface of the panel. Since this sensor was not isolated from the surrounding, unlike other sensors, so it read the average temperature between the surrounding and the front surface of the panel. Monitoring and maintaining the temperature of this sensor at 45°C by the control of the Arduino has reduced the average temperature of the back surface of the cooled PV panel to 48.6°C.

The evaporative water cooling is characterized by low cost, easy implementation, the availability of components in the market, and the little power consumption. The feasibility of the evaporative water-cooling technique proves in **Table 3**, between different cases of water cooling. The best case is case IV, in which the greater drop in the temperature of the PV panel was achieved for about 12.6 °C resulting in an improvement in electrical efficiency to 8.67%.

Table 3. Performance Parameters for cooled PV Panel for Different Experimented Cooling Circumstances.

Case	Maximal power output(W)	Improvement in power output%	Average Panel temperature reduction(°C)	Electrical Efficiency%	Improvement in Electrical Efficiency%
Without cooling	36	/	/	7.47	/
Cooling of case (I)	36.59	1.6	4	7.6	1.74
Cooling of case (II)	37	2.7	8	7.68	2.8
Cooling of case(III)	41.63	15.6	12.2	8.65	15.8
Cooling of case(IV)	41.78	16	12.6	8.67	16

Fig.15 shows the performance response of the PV panels at the peak of solar irradiation in different cases, the highest column between the four cases is in case IV, which improves the electrical efficiency and output power of the PV panel by 16%. Similar to it is case III with slight deference in electrical efficiency of about 0.2 % and output power of 0.4%. The next is case II which is about 13% in electrical efficiency and 12.9% in output power less than case III. Lastly, case I is less case II about 1.06% in electrical efficiency and 1.1% in output power.

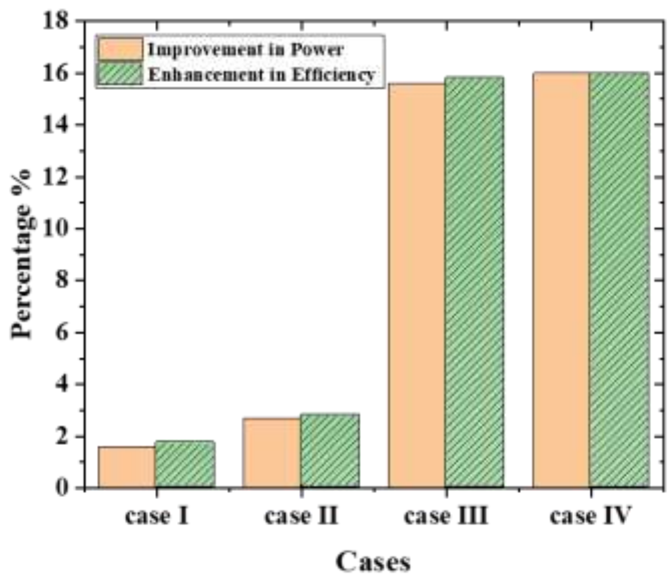


Figure 15. Experimental Performance of Cooled Panel through Four Cases.

Although pumping water, in this case, was the least among the other cases, yet it was the best since the cellulose pad was allowed to saturate more with water, and this enhanced the evaporation. In case (I) and (II) the total working time of the water pump (I) was 24 minutes from 9:00 am to 4:00 pm, and this helps to reduce the consumption of the electrical energy and no damages to the water pump.

6. CONCLUSIONS

In this research, the experiments were conducted “with and without cooling of the PV panels” during May, June, July, and August 2019. An increase in the absorption of solar radiation will increase the panel’s temperature, and that will cause a decrease in the panel’s conversion efficiency.

The analysis of the experimental results demonstrates that:

1. Water cooling techniques proved their ability to reduce PV panel’s temperature, more than 10^{o}C by evaporative water cooling.
2. The use of the evaporative water technique as a cooling system improves both the power and efficiency of the panel by about 16%.
3. The heat transfers between the PV panel and cooling system was increased with the lowest water flow rate of 3.5 LPM, in the case of the front temperature sensor and lower inlet water temperature.
4. The high wind speed enhances the evaporation rate as well as the heat transfers by convection.
5. The dust accumulated on the panels forms a layer that reduces the absorption of solar radiation and raises the panel temperature. The design of the system proposed in this research contributes to resolving this problem by using the nozzles in the front surface of the panel to clean and remove this layer of dust.
6. The design of the system proposed can be used to cool and clean the PV panels in the tropical region.

7. RECOMMENDATIONS

1. The mathematical model can be used to calculate the panel’s temperature and power and compare results with experimental results from simulate work.
2. Engineering programs such as COMSOL can be used to simulate panel temperature and solar radiation.
3. In addition to the experimental results obtained when cellulose pad is used, further experiments can be done on C panel using other types of materials, such as sponge or cotton, and compare the results.
4. Hot outlet water can be used, after cooling the panels, in a domestic application.
5. Water from well can be used instead of the water from underground tank.
6. Added high-capacity storage batteries and an inverter to the system to provide electricity when it becomes dark, therefor the PV panel electrical output power can be used in household appliances and equipment. This can be very useful in remote areas where there is no alternative to other energy sources.

NOMENCLATURE

A	=Area	,m^2
AM	=Air Mass	, Dimensionless
E	=Efficiency	,%
I_m	=Maximum Current	, A
I_{sc}	=Short Circuit Current	, A
P_m	=Maximum Power	, W
R	=Sun Radiation	, W/m^2

T	=Cell Temperature	, °C
V_m	=Maximum Voltage	, V
V_{oc}	=Open Circuit Voltage	, V

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