Assessment Cooling of Photovoltaic Modules Using Underground Water

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Abstract

Purpose: The drop in photovoltaic energy conversion efficiency under actual operating conditions because of cell temperature increase is a significant challenge to PV adoption and utilization. In this study, the efficiency and effectiveness of using underground water in cooling and cleaning photovoltaics will be practically ascertained in Baghdad-Iraq.

Method: The cooling mechanism utilizes copper pipes in a modified spiral flow configuration. This developed system is referred to as Photovoltaic thermal (PV/T). To study the effect of using underground water wells on the performance of the PV system, two wells were drilled four meters apart to prevent the interference of cold well water and hot water from the heat exchanger. The water is drawn from the first well, with a depth of 8.86 m, and the hot water flowing out of the collector is injected into the ground through the second well, which has a depth of 8.43 m.

Results: The outcome reveals that relying on a cooling source with a constant - low temperature (21°C) offers excellent cooling for the PV module, compared to an uncooled PV module, by 6°C at 7:00 AM and increased to reach 22°C at 1:00 PM. This reduction in temperature resulted in an average increase in electrical efficiency by 16.7%. The thermal efficiency ranges from 14% at 7:00 AM to 58% at 2:30 PM.

Conclusion: The findings suggest that this approach is energy efficient and effective during the summer season.

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Introduction

Solar collectors that use solar radiation to heat water or air are commonly used technologies. These collectors consist of heat exchangers that convert solar energy into heat through an absorption plate and is then transferred to a fluid (air or water) in contact (Somwanshi & Sarkar, 2020). Photovoltaic (PV) cell technology has become accepted by the general public as well as decision-makers, and its installation projects began to expand to large-scale plants and spaces. PV technology's electrical power is expected to reach, worldwide, about 1.27 TWh by 2022 (Sailor, et al., 2021). This acceptance and rapid spread have its reasons, including that PV technology relies on a free and available source, which is sunlight. It is positioned to be an alternative energy source to fossil fuels in the future as it can also achieve safe and sustainable development by meeting the increasing global demand for energy and reducing the need for reliance on fossil fuels. It is also becoming more attractive as solar modules' electricity generation efficiency increases and costs are reduced (Abdo, et al., 2020 A). One of the drawbacks of the PV cell is that the efficiency of its sunlight to electricity conversion does not exceed 15 % in stable operating conditions, while the rest is converted into heat that heats the surface of the PV (El Kharaz, et al., 2021). When the temperature of the photovoltaic plate increases, the electrical efficiency decreases, and accordingly, its voltage which leads to its degradation over time. In some cases, an increase of 1 ºC results in a decrease in efficiency of about 0.5% (Siecker, et al., 2017). In order to reduce solar module temperature, many cooling techniques have been studied and evaluated in all respects (Al-Waeli, et al., 2016).

The idea of cooling PV systems was proposed in the 1970s and is still under development today (Jia, et al., 2020). The temperature reduction of PV modules using water, air, nano-fluids and Phase Change Material (PCM) has been studied and experimented. However, criteria must be adopted to choose the right system, such as cost, simplicity in manufacturing, and system life (Al-Waeli, et al., 2019 A). Various cooling methods have been introduced to mitigate the costs associated with other systems which require more components (Ahmad, et al., 2021). However, water cooling of photovoltaics is considered as the most favorable method; it is more efficient in heat transfer. Water cooling is also better than nanofluids and nano enhanced PCM because of its lower cost compared to the two. Potential issues that arise from using advanced nano-enhanced PCM includes being careful not to crystalize the added material and avoiding nano-material precipitation with time. The same is applied to nanofluids, as many studies have shown that all nanofluids have their thermal conductivity decreases with time, which calls for them to be discharged from the system and re-mixed. If we consider PV systems, for example in 500 MW application, and considering high mass use of nanoparticles that add the cost of kWh, then it is reasonable to conclude that using water to cool PV modules is a favorable option (Al-Waeli, et al., 2018; Al-Waeli, et al..,, 2017 A).

Photovoltaic cooling systems have proven their capabilities in containing the high temperatures of the PV module. Bevilacqua et al. (Bevilacqua, et al., 2020) studied the differences in the performance of the photovoltaic module when cooled by different techniques. They used spray cooling and forced ventilation on the back surface of the PV panels. The results showed a clear decrease in the temperature of the cooled panels up to 26.4°C, which increased the electrical efficiency of the module by 14.3% compared to 12.7% for the experiments held in August. Jurcevic. (Jurčević, et al., 2021) proposed a cooling technique based on using a hybrid - cooling system adopting the addition of phase change material (PCM) and water cooling. The theoretical study of several natural factors such as wind speed, angle of inclination of the PV module, relative wind angle has been studied and were found to affect the performance of the system. Experimentally, they carefully measured the convective heat transfer coefficients in the wind tunnel of a free-standalone PV module. The study concluded that the average deviation between theoretical measurements and experimental data is about 12%, which represents the accuracy of the developed numerical model to a reasonable degree.

Nahar. (Nahar, et al., 2017) used a parallel plate water flow cooling system at a solar radiation intensity of 1,000 W/m2. The electrical efficiency was found to improve by about 20%, while the thermal efficiency had reached 73%. They concluded that reducing the solar panel's temperature by 1°C causes an increase in the generated power up to 1.9 W. Mohanraj (Mohanraj, et al., 2019) used water cooling of the PV cell in two regions, the upper and the lower part. They concluded that cooling the lower part of the PV module with water results in an improvement in the performance of the system compared to cooling the upper part. Lubon. (Luboń, et al., 2020) studied water cooling of solar panels to assess how the system has improved. They used tap water that was poured onto the surface of the photovoltaic panel to form a water flow. In the second case, the rain was imitated, and the results were compared to an uncooled PV. The results showed a decrease in the temperature of the cooled panels up to 25° C compared to the non-cooled panel, where its temperature reached 45°C. The best decrease in the temperature of the PV module is for the water flow cooling condition; the equipped power increased up to 20%. The increase of PV output due to cooling has been verified and established in multiple experimental investigations (López, et al., 2011; Othman et al., 2016).

Moreover, the heat transfer fluid that absorbed the heat from the process of cooling the PV module can be used for thermal energy applications. Different working fluids (Hemmat Esfe, et al., 2020) and flow configurations (Poredoš et al., 2020) are topics that researchers in this field are constantly studying. An appropriate cooling channel design can improve the heat transfer and lead to uniform temperature distribution, achieving better cooling of the PV module. Typical flow arrangement includes direct-flow, oscillatory-flow, spiral-flow, web-flow, etc. (Sachit, et al., 2020). Ibrahim (Ibrahim, et al., 2010) numerically simulated the cooling of a PV module with three different types of absorber flow configurations: The Spiral, Oscillatory and web-flow absorbers (Bhattacharjee, et al., 2018). The authors found that in controlling the different independent parameters, the highest electrical efficiency was the Spiral-flow design, followed by the web-flow design, and last is the oscillatory-flow design. Due to its performance and ease of construction, many authors have used the spiral-flow design in novel PV/T collectors with other features (Ibrahim, et al., 2018; Das et al., 2021). Moreover, in recent literature (Lateef, et al., 2020 ; Abdullah, et al., 2019; Nahar, et al., 2017), the combination of different design patterns (hybrid or customized) to produce suitable novel flow configurations for either thermal or electrical performance, total improvement, or to suit specific environmental conditions has been studied.

The above studies have concluded that distilled water for cooling PV systems is an efficient and practical technique. However, distilled water today is not a freely traded commodity. Instead, it is an important source that is decreasing daily due to the increase rapid rate of population and the water consumption increase in per capita - due to the improvement of the economic situation. It is expected that the future wars will not be over oil but over water resources. The idea of the present study revolves around this point, as it suggests the use of groundwater near the earth surface to cool the PV module. Certainly, cooling the PV cells means absorbing the heat gained from the insolation, and thus the effluent "hot" water, absorbed from the PV cells, is either used or sent to the sewers, which means a waste of essential and expensive material. This study suggests recycling it and injecting it into the ground to be cooled and reused. Also, in this study, the efficiency and effectiveness of using underground water in cooling and cleaning photovoltaics will be practically ascertained in Baghdad-Iraq. Iraq is considered one of the countries with large dust storms, and its dusty days exceed 100 days annually (Chaichan, et al., 2018). The contribution in this study is not the water-cooling technology, which has been well studied and researched, but in the source of water and the process of preserving it from waste.

Experimental Setup

1. Study Site

Iraq is one of the countries in West Asia and overlooks the Arabian Gulf (Kazem & Chaichan, 2012), as shown in Figure 1. The study was conducted in Baghdad, the capital, which has an administrative land area of 5,159 km2 and extending between latitudes 33° 10' - 33° 29' N and longitudes 44° 09' - 44° 33' E. Baghdad has an estimated population of 7 million, equivalent to 24% of the country's population (Alnasser, et al., 2020). It is characterized by a dry and semi-arid climate with hot, dry summers and short, cold winters. The average rainfall per year is 151.8 mm (Ali & Al-tawash, 2013). Ambient temperatures range from below 0 °C in winter to 55 °C in summer. The area is geologically represented as the sedimentary flood plain. The study area has high solar radiation intensity, like the rest of central and southern Iraq near the sunbelt, ranging from the lowest daily value at noon of 286 W/m2 in winter to 890 W/m2 in summer, with an average annual sunshine hour of 8.7 h/day. The average annual wind speed for the city is 3.1 m/s and the average annual relative humidity is around 44.3%. Baghdad suffers from frequent dust storms and a continuous rise of dust throughout the year due to the presence of the Anbar desert in its west (Chaichan & Kazem, 2018).

Underground water in Iraq is used for irrigation, drinking and household purposes in many of its regions. It contributes a significant portion of the country's drinking and irrigation water supply. Also, because most of the lands of Iraq are sedimentary plain, most of this water is of high quality, and the changes in the salt concentrations and components are minimal during seasons, and it is a reservoir of water near the surface of the earth (less than 10 m to 20 m only). This water is preserved at low temperature, not exceeding 20°C at all seasons. The capital of the country, Baghdad, represents the largest population and industrial density area and can be divided into urban, agricultural, and industrial areas with rates of 72.69%, 25% and 2.31% respectively, of the total area of the governorate (Ali & Al-tawash, 2013). Figure 1 shows a map of Iraq with the depth of the underground water reservoirs and notes that Baghdad can reach its groundwater by drilling wells less than 10 m deep (Saleh, et al., 2020). Baghdadis have become accustomed to digging such wells during the many wars that the country has fought for the period from 1980 to today. There is currently a severe move to build several photovoltaic power stations. One of the concerns of not immediately engaging in installing PV modules at a very large scale is that they are affected by high solar radiation and high temperatures during most of the year, questioning their utility and feasibility (Chaichan & Kazem, 2020; Alnasser, et al., 2020). Therefore, the use of underground water for cooling PV modules stands as a good solution. This point has not been studied thoroughly internationally due to the need to drill water wells at high depth, while in the case of Baghdad, the wells need to drill at a distance of only 8.33 m.

Figure 1. Iraq map with the distribution of underground water depths.

2. System Description

Two PV modules were used in this study, directed to the south and at an angle of 33° to fit the tilt angle of Baghdad. The used modules are monocrystalline type PLM-100/12; the maximum generated current, voltage and power are 5.29A, 19.8V, and 100W, respectively. Several thermocouples are connected (type K has a range of –200°C to +1350°C and uncertainty of ± 0.93°C) on the surface and back of the PV modules as well as measuring the water entering and leaving the cooling system's collector. The relative humidity was measured using the Relative humidity & air temperature sensor types RHT2 and AT2 for the range of relative humidity 0 to 100% RH, temperatures -20 to + 80°C, uncertainty of ± 2% RH, and ± 0.5% °C for temperature measurements. Also, a solar irradiance meter (G) type BF5 sunshine sensor was used to measure the global and diffuse solar irradiance. The BF-5 sensor has a range of 0-1250 W/m2 and uncertainty of ± 0.5 W/m2, was used in practical experiments. A US Hunter type flow rate sensor is used to measure the flow rate of cooling water for one of the PV modules, with a range of 0.83 - 80 L/min, with an uncertainty of + 0.66%. Figure 2 (a) shows a diagram of the underground cooling system, Figure 2 (b) illustrates the collector cross-sectional view, Figure 2 (c) shows the measurements of the used heat exchanger and Figure 2 (D) illustrates a photo of the PV module with backside cooling system by the flow of underground water.

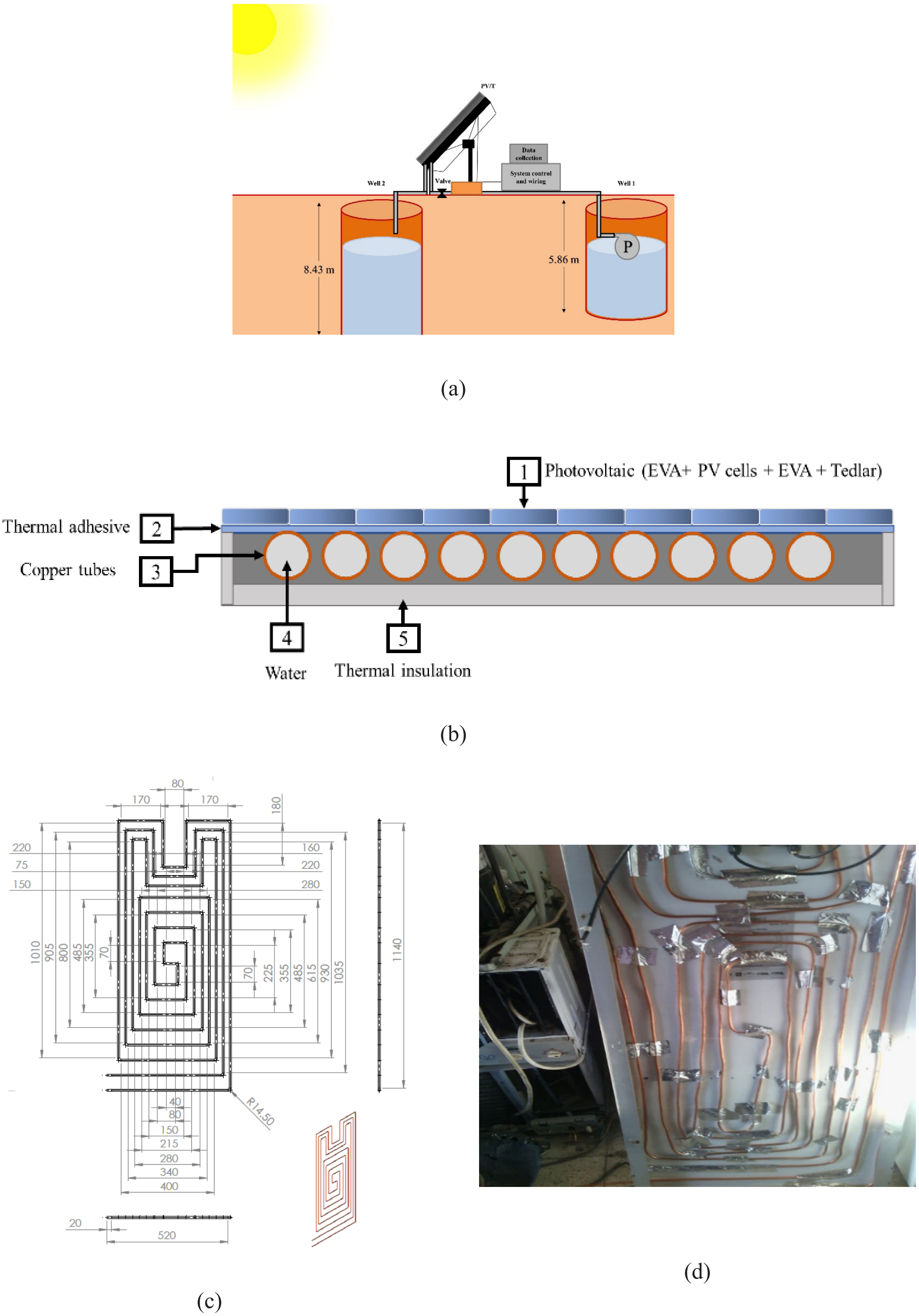

Figure 2. System and collector design and configurations (a) schematic drawing of the setup, (b) cross-sectional drawing of the PV/T, (c) Collector design dimensions in mm, and (d) photograph of collector manufacturing process.

3. Underground water wells

In order to study the effect of using underground water wells on the performance of the PV system, two wells were drilled four meters apart to prevent the interference of cold well water and hot water from the heat exchanger. The water is drawn from the first well, with a depth of 8.86 m, and the hot water flowing out of the collector is injected into the ground through the second well, which has a depth of 8.43 m. Indeed, the hot water resulting from the cooling process can be used in multiple applications, but in this study, the water was injected back into the ground instead of being sent to the sewers. The process of drilling a well to a small depth (such as our two wells) is inexpensive, and many digging wells companies are highly available in Baghdad. The walls of the two wells are supported by a 10.28 cm (4 in) plastic tube. Two plastic hoses with a diameter of 1.285 cm (0.5 inches) were used for cold water extraction and hot water injection. A water pump was used to draw the groundwater and circulate it into the heat exchanger, and the flowing water mass was controlled using a manual valve. The groundwater comes out sometimes loaded with dirt, so a filter was placed through which the water passes before entering the exchanger. The groundwater was pumped into an insulated tank to maintain its temperature, and after it was complete, the water was pumped into the heat exchanger.

4. Hydraulic measures pump selection

In order to determine the hydraulic measurements, there is a need to specify many parameters such as pump efficiency, suction pressure, pump head, working hours per day, the volume of water required per day, etc. The following equation was used to determine the needed pumping power (Al-smairan, 2012):

$$P_{pump} = \frac{\rho g (h + \Delta H) Q}{\eta_p . \eta_e} \text{ (kW)}, \tag{1}$$

where ρ is water density (kg/m^3), g acceleration due to gravity (m/s^2), h is the well depth (m), ΔH total pumping head (m), Q is the flow rate (kg/s), ηp and ηe are pump and electric motor efficiencies, respectively. The hydraulic energy in (kWh/day), required for the studied system was calculated by the formula:

$$E_h = \eta_s . E_{PV} = \rho g h V \eta_s \tag{2}$$

Where V in (m3/day) is the volume.

The electricity generated by the photovoltaic array is of direct current, and this current is converted into alternating current using an inverter. So, the productivity of the PV array was calculated using the following equation (Kazem, et al., 2013):

$$E_{PV} = A_{PV} \times G_T \times \eta_{module} \times \eta_{inv} \times \eta_{wire} \quad \text{(in kW)} \tag{3}$$

The following formula can be utilized to calculate A_{PV} :

$$A_{PV} = \frac{\rho g h V}{G_T \eta_{PV} \eta_s} \text{ m}^2), \tag{4}$$

where APV, and GT, are the PV area in (m^2) and insolation in (kW.h/m^2). The total power of the photovoltaic array required to operate the pump is calculated by the equation:

$$P_{PV} = \frac{E_h}{G_T . F . E} \text{ (kW)}, \tag{5}$$

where F is mismatch factor (0.85-0.90) and E is the daily subsystem efficiency (0.2- 0.6).

The system efficiency (PV/Pump) calculated by

$$\eta_{system} = \frac{P_h}{P_V} = \frac{\rho g h V}{G_T A_V} \quad (\%) \qquad (6)$$

Where Ph is the hydraulic power. The required pumping power was calculated from equation (6), and it was 2.197 kWh/day using Equation (2). The system pump rating is 200 W. The required photovoltaic array power was 0.88 kW according to Equation (5). Therefore, a PV array of three panels at least (0.3 kW) connected in series is required to operate the pump. The pump that draws water from a well (with a depth of 8.33 m) has a static water level of 7 m and a dynamic water level of 7.5 m. The well produces 8.0 m^3/h with a pump head of 18 m.

5. Test Procedure

At 6:00 AM, the pump is turned on during all testing days; the underground water is drawn in, the tested PV units are washed and then wiped by a plastic wipe to remove any dust accumulated on their surface. Measurements start from 7:00 AM until 6:00 PM, during which readings are taken for different temperatures (air temperatures, water entering and leaving the heat exchanger, the temperature of the surface of the PV panel and its backside), the solar radiation intensity and relative humidity. Readings of the current, voltage and power generated by the two systems are also taken. These measurements were undertaken every 30 minutes.

Results and Discussions

Figure 3 shows the measured average global and diffuse solar radiation and relative humidity of the outdoor environment through the testing period. The figure shows that the daily average of the total global solar energy is 5,845 Wh/m^2 (5.845 kWh/m^2), and the daily average diffuse solar energy is 3,127 Wh/m^2. The relative humidity of the city of Baghdad is relatively high in the early morning (66% at 6 AM) and drops to its lowest levels at peak time, reaching 42% between 1:00 – 4:00 PM. This humidity is suitable for photovoltaic cells and does not reduce their service life. The measurement conditions were suitable in terms of solar radiation, relative humidity, and clear air from dust.

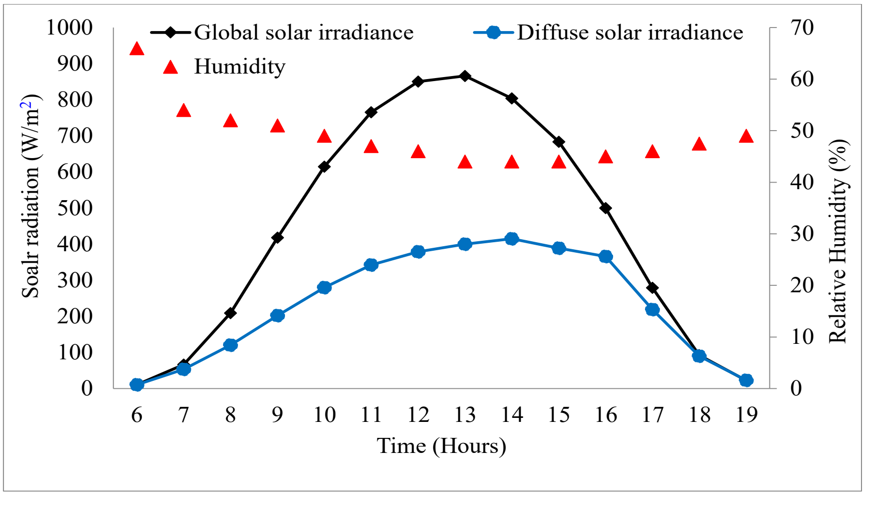

Figure 3. The measure average global and diffuse solar radiation and relative humidity.

The first practical experiments with the PV/T system are to find the optimum system flow rate. There is a critical balance between the flow rate of cooling water and the cooling rate of the PV unit. The higher the flow rate, the higher the cooling rate, but in reality, it is not. As the fluid flow rate increases, the flow velocity increases and the heat exchange time between the back surface of the PV module and water decreases. Therefore, it was necessary to look for a flow that gives the highest decrease in the temperature of the PV module while preserving the system from vibrations that may cause damage. The results of Fig. 4 show that both 0.14 and 0.16 kg/s gave the best cooling effect for PV modules in the system. However, practical experiments showed the emergence of vibrations in the studied system work with a flow of 0.16 kg/s, so the water flow rate of 0.14 kg/s was chosen in all the remaining experiments. Vibrations in the system are generated by the movement of the cooling fluid and depend on its speed, and their appearance depends on the supports used in setting up the system. These vibrations can be eliminated using damping techniques, which was not taken into account in this study. Allowing the system to increase its vibration may lead to reach the resonance point at which it will be destroyed, therefore, using low flow velocity represents a kind of vibration control and protection for the system; which is considered as a limitation.

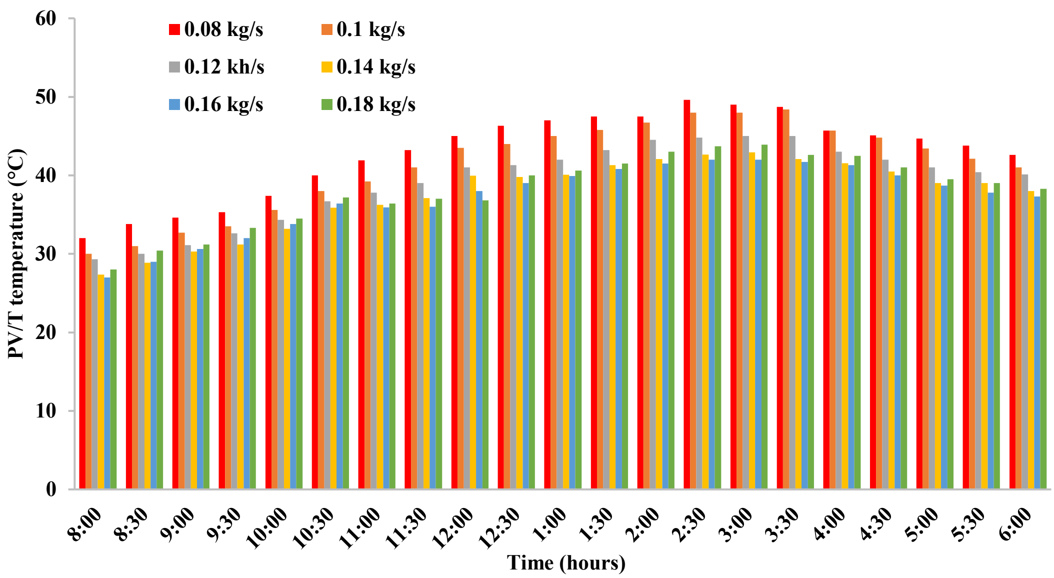

Figure 4. The effect of water mass flow rate on the PV/T module temperature.

Figure 5 shows the temperature gradient of the two tested systems compared to the ambient air temperature of Baghdad in June 2020. This month, the work was done due to the high ambient temperatures, which reached a maximum of 46.3°C and a minimum value of 33.5°C. While the solar radiation intensity reached a very high value, as the maximum intensity measured was 987.1 W/m2 (at noon). The maximum temperature that a PV panel reaches is 66.3°C at 1:00 PM. As for the PV/T system's panel, the maximum temperature reached was 47.31°C at 12:30 PM. The lowest temperatures difference of the PV/T system for the entering and exiting water was 6.37°C at 7:00 AM, and the most significant difference was at 3:00 PM (22.93°C). The stability of the underground water at a temperature of approximately 21°C makes the difference between it and the temperature of the PV module very high, which increases the heat flow rate from its to the cooling water and, as a result, reduces the temperature of the module and increasing its efficiency.

The highest temperature difference of PV modules for the two systems (which was at 1:00 PM) in favor of the PV/T system with a difference of 21.8°C. The cooling effect of the groundwater to the PV/T system is high and suitable for working in the harsh weather conditions of Baghdad.

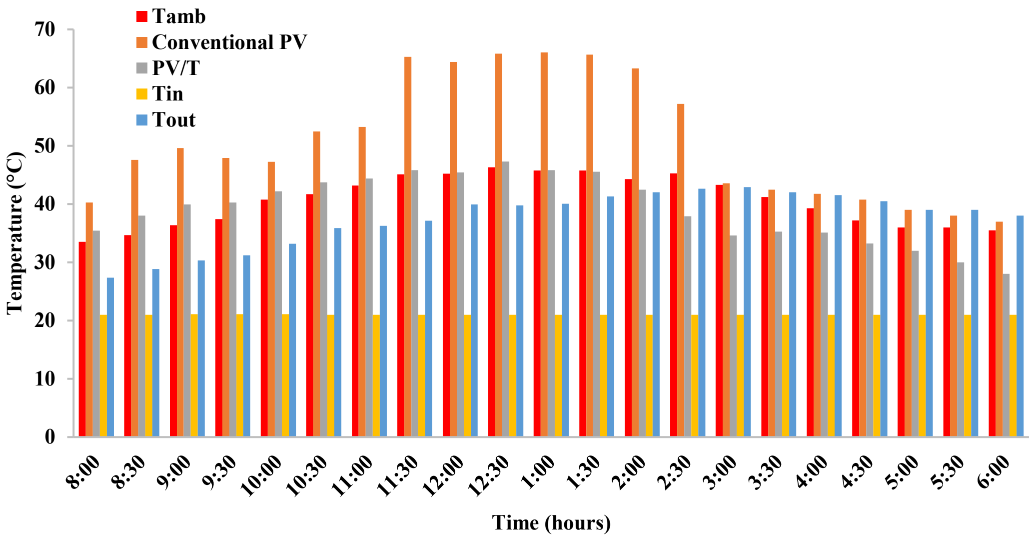

Figure 5. Measured temperatures variation with time for the tested systems.

It has to be noted that the increases in temperature of the PV cell (Semiconductor) reduces the bandgap of a semiconductor, i.e. decrease the bandgap of a semiconductor. In the bond model of a semiconductor bandgap, a reduction in the bond energy also reduces the bandgap (Al-Waeli, et al., 2017 B)PCM has been employed with a cooling nanofluid circulation system in order to the control heat capacitance of the system to maintain electrical efficiency on the one hand, and to raise the overall efficiency on the other. Nano-SiC particles were used in paraffin-PCM and nanofluid to establish higher thermal conductivities and therefore higher efficiency. The design is tested outdoors in Selangor, Malaysia. The tests were conducted using a fluid flow rate of 0.17 kg/s. The proposed system reduced the cell temperature (30 °C. Therefore, increasing the temperature reduces the bandgap. For PV cells, the open-circuit voltage is the parameter that is affected most by an increase in temperature. Our observation shows that the current (I) of PV cells increases as temperature deceases while the voltage increases as temperature decreases.

When solar cells are subjected to an increase of the temperature, the PV current will increase insignificantly, while the PV voltage will decrease significantly. Since voltage decreases faster than the current increases, the solar cell will have a lower efficiency for PV module. PV voltage is directly proportional to resistant according to Ohms low (V=IR) and resistance increases with the increase of temperature due to increased vibrations of the molecules inside the conductor. Therefore, voltage increases as temperature increases.

The effects of temperature on the voltage, current and power output of the module can be understood from the following relations (Chaaban, 2022):

$$I = ISTC + IT\text{-}coeff \times (TCell - 25)\ °C \quad (7)$$

$$V = VSTC + VT\text{-}coeff \times (TCell - 25)\ °C \quad (8)$$

$$P = PSTC + PT\text{-}coeff \times (TCell - 25)\ °C \quad (9)$$

The terms ISTC , VSTC and PSTC refer to the Current, Voltage and Power taken at Standard Test Condition (STC) while the temperature coefficients of the current ,voltage and power are represented by IT-coeff , VT-coeff and PT-coeff, respectively. For example, If ISTC is 3 A, so at T= 40° C with IT-coeff = 0.006 A /°C , then I= 3.09 A ; For V, if VSTC = 0.46 V, so at 40 °C with VT-coeff = - 0.002 V/°C , then V= 0.42 V; for P, if PSTC =240 W, so at 40 °C with PT-coeff = -2 W/°C, then P = 210 W.

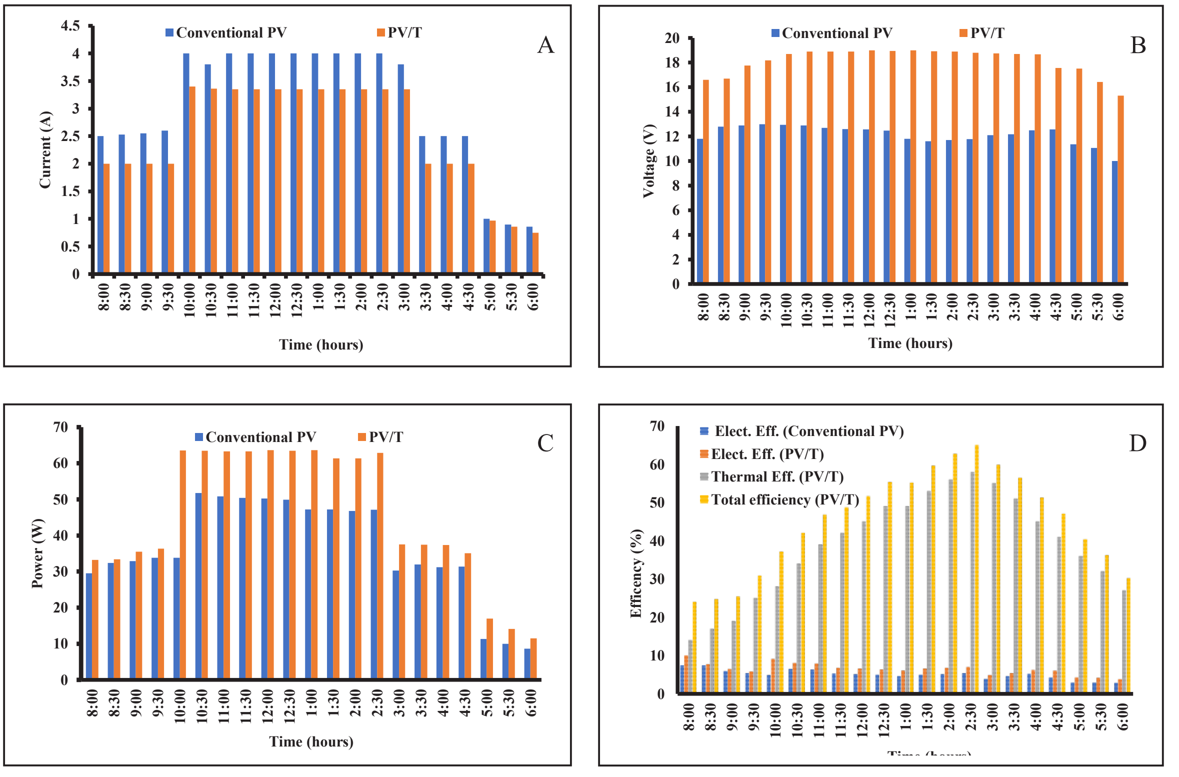

Figure 6. Measured Parameters variation with time for two PV modules; Conventional and Cooled PV (PV/T).

Figure 6 shows the measured performance parameters of the two studied systems (the cooled PV and the uncooled PV or Conventional PV), including current, voltage, power, and efficiency. Photovoltaics are affected by insolation; the higher the radiation intensity, the higher power produced with relatively more power (26.34% more) for cooled PV system (Figure 6C). For a whole day's operation, the difference in current supplied from both systems was 2.8% in favor of the non-cooled PV system as shown in Fig 6 A. This observation agrees with equation (7) and also agrees with the theoretical derivation of the effect of temperature on PV current (Al-Waeli, et al., 2017 C), which shows that for silicon solar cells the open circuit current (I0) approximately doubles for every 10 °C increase in temperature according to the following relation (Honsberg & Bowden, 2022):

$$I_0 = qA\frac{D}{LN_D}BT^3\exp\left(-\frac{E_{G0}}{kT}\right) \approx B'T^{\gamma}\exp\left(-\frac{E_{G0}}{kT}\right), \qquad (10)$$

where q is electronic charge, A is the area, L is the minority carrier diffusion length, N_D is the doping, ni is the intrinsic carrier concentration given for silicon, T is the temperature; k is a constant; E_{GO} is the bandgap linearly extrapolated to absolute zero , B´ is a constant (independent of temperature), and γ is used instead of the number 3 to incorporate the possible temperature dependencies of the other material parameters. For the short circuit current there is also a slight increase as temperature increases (dI/dT = 0.0006 / °C increase for silicon). This observation is also supported by other commercial manufactures' reports (Boston Solar, 2019) which states that the temperature coefficient of LG NeON® 2 solar panels is - 0.0038% per each °C (decrease in current with temperature) ,i.e. every 1° C above 25°C, the maximum efficiency of an LG NeON® 2 solar panel decreases by 0.38% and for 1° C below 25°C, the maximum efficiency of that solar panel will increase by 0.38%.

In our work, the voltage generated by PV cells increases as the temperature of the PV module decreases, as shown in Figure 6B. The high cooling of the groundwater of the PV/T module caused an increase in the generated voltage of the system by 49.26% compared to a standalone PV module. This observation agrees with equation (8) as well as agrees with the theory (Honsberg & Bowden, 2022), which shows that the temperature sensitivity of a solar cell depends on the open-circuit voltage of the solar cell, with higher voltage solar cells being less affected by temperature; For silicon, EG0 is 1.2 (E_{G0} = q V_{Go}) and using γ as 3 gives a reduction in the open-circuit voltage will increase about 2.2 mV per 1 °C increase (Honsberg & Bowden, 2022);

$$\frac{dV_{OC}}{dT} = -\frac{V_{GO} - V_{OC} + \gamma\frac{kT}{q}}{T} \approx -2.2mV\ per\ ^{\circ}C\ for\ Si \qquad (11)$$

The decrease in the voltage with temperature is due mainly to the changes in the intrinsic carrier sconcentration, n_i. The variation of ni with dV_{oc} /dT is shown in Fig. 7 (Honsberg and Bowden, 2022).VOC deceases with T due to increase with ni with temperature – as understood from the following relations (Sproul & Green, 2012; Honsberg & Bowden, 2022):

$$VOC_1 = (kT_1/q)\ \ln(I_L/An_{i2}) \qquad (12)$$

$$n_i = 9.38\,e19\,(T/300)^2\,e^{-6884/T} \qquad (13)$$

$$VOC1 = (nkT/q)\ \ln(I_L / A.\,9.38\,e19^2\,(T/300)^4\ e^{-6884/T}) \qquad (14)$$

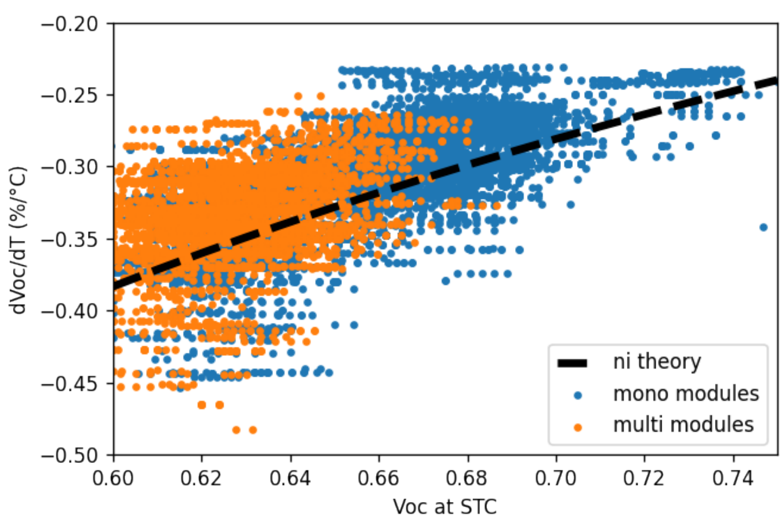

Figure 7. Change in V_{oc} with temperature compared with the prediction from n_i change with temperature (Honsberg & Bowden, 2022).

The noted increase in the PV module efficiency with cooling (Fig 6 C) agrees with equation (9); as the temperature of the module decreases, the power produced is higher. The use of cold groundwater during the summer of Baghdad has proven excellent results that substitute for nanofluids in heat transfer and the adoption of an improvement in the rate of heat transfer due to the difference in temperature only.

The PV system provides only electrical efficiency while cooling systems have thermal and overall efficiency when taking advantage of the heat absorbed from the system (Figure 6D). In the studied cooled system, water was injected into the ground, as there was no application to benefit from it in practice. However, in the experimental conditions of the PV/T plants, the amount of heat absorbed will be high, and it can undoubtedly be used to operate small electricity-generating turbines or absorbent cooling systems operating with hot water. It is noted that the electrical efficiency of the studied PV/T system is higher than its counterpart by about 27.62%. As for the highest thermal efficiency reached, it was 58% at 2:30 PM. The overall highest efficiency was 65% at the same hour.

Comparison with literature

The comparison between the performance of photovoltaic systems is a complex process, as the photovoltaic modules produced from the same factory and production line show a variation, albeit very limited, in the electrical power generated under the same operating so how is the case with different types and conditions. In general, a comparison with other studies can give a positive or negative indication of the results of the current work. Figure 8 shows a comparison adopted for two indicators, the average improvement in electrical efficiency (%) and the average temperature decrease of the cooled PV module (°C). The comparison was based on studies that used different cooling methods and cooling fluids. For example, (Nada, et al., 2018) used PCM with nanoparticles, (Fayaz, et al., 2019) used the only PCM, and (Ragab, et al., 2019) used nanofluid consisting of water and activated alumina. In Abdo's work (Abdo, 2020 B), the used Hydrogels was added to water; whiles in Abdo's other work (Abdo, et al., 2020 A), saturated activated alumina with saline water was used to cool down the PV/T system. Al-Waeli (Al-Waeli, et al., 2019 C) used water as a cooling fluid, while Lateef (Lateef et al., 2020) used a dual solar collector (air + water). Al-Waeli (Al-Waeli, et al., 2019 B) used nanofluid and nano-PCM to cool the PV/T system. Somwanshi & Sarkar (Somwanshi & Sarkar, 2020) utilized multi-wall carbon nanotubes (MWCNT) with water/glycol as the base fluid. The comparison confirms that the current study's findings gave excellent results due to its dependence on running water at a low temperature (groundwater) and without water recycling.

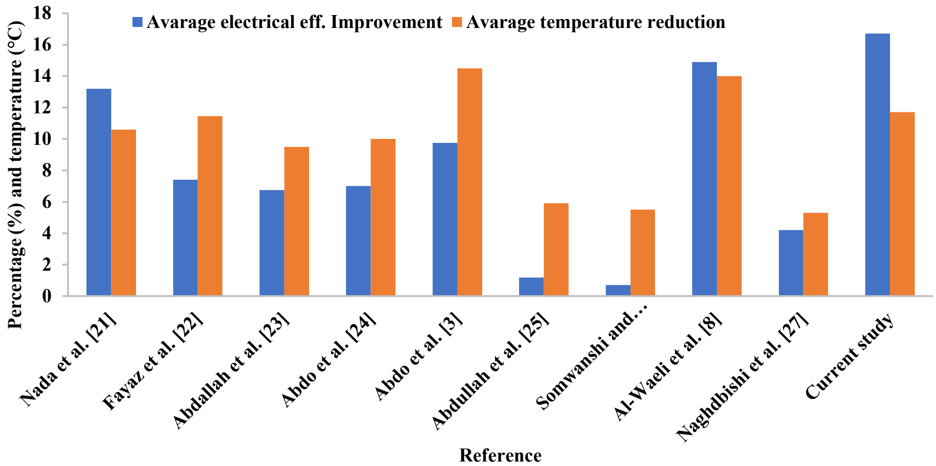

Figure 8. Comparison of the current study results with some studies in the literature

Conclusion

The current paper studied, experimentally, the advantage of using groundwater as a cooling working fluid in PV/T systems for PV modules. It supports the use of using groundwater from about 9 m deep well. The effluent liquid “relatively hot water” can be utilized for other purposes “heating” or reinjected to be cooled and reused.

The result of this study is a showcase of the possibility of employing underground water as a cooling mechanism in Baghdad, as the electrical efficiency of the studied PV/T system increased by about 27% compared to a PV module without cooling. This increase in efficiency is due to the decrease in the temperature of the cooled PV unit from about 6 °C at 7:00 AM to about 22 °C at 1:00 PM. An average of 11.7°C decreases in the temperature of the PV module for a day of operation has been found when using ground water as a cooling fluid. This system can supply the effluent warm water (after absorbing heat from PV panels) for various purposes, including residential and agricultural demands. Future studies can focus on the life cycle cost analysis of this system and its utilization for an array of PV modules or for large scale power plants.

Since the climate of Baghdad do not vary much as other Gulf Cooperation Council Countries (Oman, Bahrain, Saudi Arabia, UAE, Kuwait, and Qatar) (Al- Olaimy, 2021; Raouf, 2008; Alharbi and D Csala, 2021) – where it is nearly warm and hot about 6 months a year and relatively cold about a month per year – then this cooling system (with deeper wells) can be utilized for future PV installation (PV/T) to have better Solar Electricity yield due to increase in PV efficiencies.

References

Al- Olaimy (2021) Climate Change Impacts in the GCC, EcoMENA , https://www.ecomena.org/climate-change-gcc/ (Accessed in Feb 2022).

Abdo, S., Saidani-scott, H., Borges, B., & Abdelrahman, M. A. (2020 A). Cooling solar panels using saturated activated alumina with saline water : Experimental study. Solar Energy (208) 345–356. https://doi.org/10.1016/j.solener.2020.07.079

Abdo, S., Saidani-scott, H., Benedi, J., & Abdelrahman, M. A. (2020 B). Hydrogels beads for cooling solar panels : Experimental study. Renewable Energy, 153: (777–786).

https://doi.org/10.1016/j.renene.2020.02.057

Abdullah, A. L., Misha, S., Tamaldin, N., Rosli, M. A. M., &, & Sachit, F. A. (2019). Thermal Efficiency and Heat Removal Factor for Hybrid Photovoltaic Thermal PVT System. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 58(1):51–61.

Ahmad, E. Z., Sopian, K., Jarimi, H., Fazlizan, A., & Elbreki, A. (2021). Recent advances in passive cooling methods for photovoltaic performance enhancement. International Journal of Electrical and Computer Engineering (IJECE) 11(1): 146–154. https://doi.org/10.11591/ijece.v11i1.pp146-154

Al-smairan, M. (2012). Application of photovoltaic array for pumping water as an alternative to diesel engines in Jordan Badia , Tall Hassan station : Case study. Renewable and Sustainable Energy Reviews 16 (7):4500–4507. https://doi.org/10.1016/j.rser.2012.04.033

Al-Waeli, A. H., Sopian, K., Kazem, H. A., & Chaichan, M. T. (2016). Photovoltaic solar thermal (PV/T) collectors past, present and future: A review. International Journal of Applied Engineering Research 11(22):10757-10765.

Al-Waeli, A.H.A., Kazem, H. A., Sopian, K., & Chaichan, M. T. (2017 A). Techno-economical assessment of grid connected PV/T using nanoparticles and water as base-fluid systems in Malaysia. International Journal of Sustainable Energy 37(6):558–575. https://doi.org/10.1080/14786451.2017.1323900

Al-Waeli, A.H.A., Sopian, K., Chaichan, M. T., Kazem, H. A., Ibrahim, A., Mat, S., & Ruslan, M. H. (2017 B). Evaluation of the nanofluid and nano-PCM based photovoltaic thermal (PVT) system: An experimental study. Energy Conversion and Management 151 (November 2019):693-708. https://doi.org/10.1016/j.enconman.2017.09.032

Al-Waeli, A.H.A., Sopian, K., Kazem, H. A., & Chaichan, M. T. (2017 C). Photovoltaic/Thermal (PV/T) systems: Status and future prospects. Renewable and Sustainable Energy Reviews 77 (September 2017) :109-130. https://doi.org/10.1016/j.rser.2017.03.126

Al-Waeli, A.H.A., Sopian, K., Kazem, H. A., & Chaichan, M. T. (2018). Nanofluid based grid connected PV/T systems in Malaysia: A techno-economical assessment. Sustainable Energy Technologies and Assessments, 28 (2018):81-92. https://doi.org/10.1016/j.seta.2018.06.017

Al-Waeli, Ali H.A., Chaichan, M. T., Sopian, K., Kazem, H. A., Mahood, H. B., & Khadom, A. A. (2019 A). Modeling and experimental validation of a PVT system using nanofluid coolant and nano-PCM. Solar Energy 177(October 2018): 178–191. https://doi.org/10.1016/j.solener.2018.11.016

Al-Waeli, Ali H.A., Sopian, K., Yousif, J. H., Kazem, H. A., Boland, J., & Chaichan, M. T. (2019 B). Artificial neural network modeling and analysis of photovoltaic/thermal system based on the experimental study. Energy Conversion and Management 186(February): 368–379. https://doi.org/10.1016/j.enconman.2019.02.066

Alwaeli, Ali H. A. , Hussein A. Kazem, M. T. C. and K. S. (2019 C). Photovoltaic / Thermal (PV / T) Systems: Principles, Design, and Applications (1st ed.). Switzerland: Springer Nature.

Alharbi, F.R. and Csala, D. (2021) Gulf Cooperation Council Countries' Climate Change Mitigation Challenges and Exploration of Solar and Wind Energy Resource Potential, Appl. Sci. 11: 2648. https://doi.org/10.3390/app11062648

Ali, S. M., & Al-tawash, B. S. (2013). Geochemical modeling and isotope analysis of the shallow groundwater aquifer of Baghdad Area. Arabian Journal of Geosciences7(5): 1811–1827. https://doi.org/10.1007/s12517-013-0925-2

Alnasser, T. M. A., Mahdy, A. M. J., Abass, K. I., Chaichan, M. T., & Kazem, H. A. (2020). Impact of dust ingredient on photovoltaic performance: An experimental study. Solar Energy195(November 2019): 651–659. https://doi.org/10.1016/j.solener.2019.12.008

Bevilacqua, P., Bruno, R., & Arcuri, N. (2020). Comparing the performances of different cooling strategies to increase photovoltaic modules electric in different meteorological conditions. Energy 195: 116950. https://doi.org/10.1016/j.energy.2020.116950

Bhattacharjee, S., Acharya, S., Potar, A., Meena, A., Bairwa, D.S., Meena, D., Bhagora, M., Meena, P. and Gautam, P.K., (2018). An investigational back surface cooling approach with different designs of heat□absorbing pipe for PV/T system. International Journal of Energy Research 42(5): 1921-1933. https://doi.org/10.1002/er.3977

Boston Solar (2019) How do temperature and shade affect solar panel efficiency? https://www.bostonsolar.us/solar-blog-resource-center/blog/how-do-temperature-and-shade-affect-solar-panel-efficiency/ (Accessed on Feb 2022) .

Chaichan, M. T., & Kazem, H. A. (2020). Experimental evaluation of dust composition impact on photovoltaic performance in Iraq. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 00(00): 1–22. https://doi.org/10.1080/15567036.2020.1746444

Chaichan, M. T., & Kazem, H. A. (2018). Generating electricity using photovoltaic solar plants in Iraq. In Generating Electricity Using Photovoltaic Solar Plants in Iraq. https://doi.org/10.1007/978-3-319-75031-6

Chaaban, M A (2022) Commercial Solar Electric Systems: Temperature and PV Performance Optimization, The Pennsylvania State University , https://www.e-education.psu.edu/ae868/node/878 (Accessed on Feb 2022)

Das, D., Bordoloi, U., Dilip, A., Hihu, H., Krishna, R., & Kalita, P. (2021). Performance investigation of a rectangular spiral flow PV / T collector with a novel form-stable composite material. Applied Thermal Engineering182(August 2020):116035. https://doi.org/10.1016/j.applthermaleng.2020.116035

El Kharaz, H., Khallaki, K., Kadiri, M. S., & Choukairy, K. (2021, April). Performance's improvement methods of PV solar panel by different cooling systems: A Review of Experimental and Numerical studies. In AIP Conference Proceedings (Vol. 2345, No. 1, p. 020039). AIP Publishing LLC.

Fayaz, H., Rahim, N. A., Hasanuzzaman, M., Rivai, A., & Nasrin, R. (2019). Numerical and outdoor real time experimental investigation of performance of PCM based PVT system. Solar Energy 179(November 2018): 135–150. https://doi.org/10.1016/j.solener.2018.12.057

Hemmat Esfe, M., Kamyab, M. H., & Valadkhani, M. (2020). Application of nanofluids and fluids in photovoltaic thermal system: An updated review. Solar Energy 199(August 2019):796–818. https://doi.org/10.1016/j.solener.2020.01.015

Honsberg, C and Bowden, S. (2022) PVCDROM by Solar Power Lab , Arizona University, https://www.pveducation.org/pvcdrom/solar-cell-operation/effect-of-temperature (Accessed in Feb 2022)

Ibrahim, A, Daghigh, R., & Jin, G. (2010). Thermal theoretical study on PV/T water based collectors. Proceedings of the 2010 American Conference on Applied Mathematics,ACM Digital Library , pp 545–551.

Ibrahim, A., Mat, S., Fudholi, A., Abdullah, A. F., & Sopian, K. (2018). Outdoor Performance Evaluation of Building Integrated Photovoltaic Thermal (BIPVT) Solar Collector with Spiral Flow Absorber Configurations. International Journal of Power Electronics and Drive Systems 9(4):1918–1925. https://doi.org/10.11591/ijpeds.v9.i4.pp1918-1925

Jia, Y., Ran, F., Zhu, C., & Fang, G. (2020). Numerical analysis of photovoltaic-thermal collector using nanofluid as a coolant. Solar Energy196(November 2019): 625–636. https://doi.org/10.1016/j.solener.2019.12.069

Jurčević, M., Nižetić, S., Marinić-Kragić, I., Čoko, D., Arıcı, M., Giama, E., & Papadopoulos, A. (2021). Investigation of heat convection for photovoltaic panel towards efficient design of novel hybrid cooling approach with incorporated organic phase change material. Sustainable Energy Technologies and Assessments 47(June): 101497. https://doi.org/10.1016/j.seta.2021.101497

Kazem, H.A., & Chaichan, M. T. (2012). Status and future prospects of renewable energy in Iraq. Renewable and Sustainable Energy Reviews 16(8): 6007-6012 https://doi.org/10.1016/j.rser.2012.03.058

Kazem, Hussein A., Khatib, T., & Sopian, K. (2013). Sizing of a standalone photovoltaic/battery system at minimum cost for remote housing electrification in Sohar, Oman. Energy and Buildings 61: 108–115. https://doi.org/10.1016/j.enbuild.2013.02.011

Lateef, A., Misha, S., Tamaldin, N., Rosli, M. A. M., & Sachit, A. (2020). Theoretical study and indoor experimental validation of performance of the new photovoltaic thermal solar collector (PVT) based water system. Case Studies in Thermal Engineering 18 (April 2020) : 100595. https://doi.org/10.1016/j.csite.2020.100595

López, C. S. P., Tenconi, L., Castro, F. Lo, Brambilasca, S., & Virtuani, A. (2011). Testing Of A Cost-effective Photovoltaic Thermal Hybrid Solar Collector Prototype. IEEE Photovoltaic Specialists Conference, 479–484.

Luboń, W., Pełka, G., Janowski, M., Pająk, L., Stefaniuk, M., Kotyza, J., & Reczek, P. (2020). Assessing the Impact of Water Cooling on PV Modules Effciency. Energies (13): 2414.

Mohanraj, M., Chandramohan, P., & Sakthivel, M. (2019). Performance of photovoltaic water pumping systems under the influence of panel cooling. Renewable Energy Focus 31(00): 31–44. https://doi.org/10.1016/j.ref.2019.10.006

Nada, S. A., El-nagar, D. H., & Hussein, H. M. S. (2018). Improving the thermal regulation and e ffi ciency enhancement of PCM- Integrated PV modules using nano particles.

Energy Conversion and Management 166(April): 735–743. https://doi.org/10.1016/j.enconman.2018.04.035

Nahar, A., Hasanuzzaman, M., & Rahim, N. A. (2017). Numerical and experimental investigation on the performance of a photovoltaic thermal collector with parallel plate flow channel under different operating conditions in Malaysia. Solar Energy 144: 517–528. https://doi.org/10.1016/j.solener.2017.01.041

Othman, M. Y., Hamid, S. A., Tabook, M. A. S., Sopian, K., Roslan, M. H., & Ibarahim, Z. (2016). Performance analysis of PV/T Combi with water and air heating system: An experimental study. Renewable Energy 86: 716–722. https://doi.org/10.1016/j.renene.2015.08.061

Poredoš, P., Tomc, U., Petelin, N., Vidrih, B., Flisar, U., & Kitanovski, A. (2020). Numerical and experimental investigation of the energy and exergy performance of solar thermal , photovoltaic and photovoltaic-thermal modules based on roll-bond heat exchangers. Energy Conversion and Management210(March): 112674. https://doi.org/10.1016/j.enconman.2020.112674

Ragab, S., Saidani-scott, H., & Benedi, J. (2019). Experimental study for thermal regulation of photovoltaic panels using saturated zeolite with water. Solar Energy 188(April):464–474. https://doi.org/10.1016/j.solener.2019.06.039

Raouf , M. (2008) Climate Change Threats, Opportunities, and the GCC Countries, The Middle East Institute Policy Brief 11: 1-15.

Sachit, F. A., Rosli, M. A. M., Tamaldin, N., Misha, S., & Abdullah, A. L. (2020). Effect of a New Absorber Design on the Performance of PV / T Collector : Numerical Comparative Study. Journal of Advanced Research in Fluid Mechanics and Thermal Sciences 71(1): 60–71.

Sailor, D. J., Anand, J., & King, R. R. (2021). Photovoltaics in the built environment : A critical review. Energy & Buildings 253: 111479.

Saleh, S. A., Al-ansari, N., & Abdullah, T. (2020). Groundwater Hydrology in Iraq. Journal of Earth Sciences and Geotechnical Engineering 10(1):155–197.

Siecker, J., Kusakana, K., & Numbi, B. P. (2017). A review of solar photovoltaic systems cooling technologies. Renewable and Sustainable Energy Reviews 79(May): 192–203. https://doi.org/10.1016/j.rser.2017.05.053

Somwanshi, A., & Sarkar, N. (2020). Thermal performance of a dual-purpose collector-cum-storage type air- water heater. Applied Thermal Engineering, 171(June 2019): 115094. https://doi.org/10.1016/j.applthermaleng.2020.115094

Sproul, A. B., & Green, M. A. (2012). Improved value for the silicon intrinsic carrier concentration from 275 to 375 K. Journal of Applied Physics 70(2): 846–854. https://doi.org/10.1063/1.349645

تقييم تبريد الخلايا الكهروضوئية باستخدام المياه الجوفية

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المُستَخلَص

الهدف: يمثل الانخفاض في كفاءة تحويل الطاقة الكهروضوئية في ظل ظروف التشغيل الفعلية بسبب زيادة درجة حرارة الخلية تحديًا كبيرًا لاعتماد واستخدام الطاقة الكهروضوئية. في هذه الدراسة، سيتم التأكد عمليا من كفاءة وفعالية استخدام المياه الجوفية في تبريد وتنظيف الخلايا الكهروضوئية في بغداد - العراق.

الطريقة: تستخدم آلية التبريد الأنابيب النحاسية في تكوين تدفق حلزوني معدل. يشار إلى هذا النظام المطور على أنه نظام حراري ضوئي (PV / T). لدراسة تأثير استخدام آبار المياه الجوفية على أداء النظام الكهروضوئي ، تم حفر بئرين على بعد أربعة أمتار لمنع تداخل مياه الآبار الباردة والماء الساخن من المبادل الحراري. يسحب الماء من البئر الأول بعمق 8.86 م ويتم حقن الماء الساخن المتدفق من المجمع في الأرض من خلال البئر الثاني الذي يبلغ عمقه 8.43 م.

النتائج: أشارت نتائج الدراسة الى أن الاعتماد على مصدر تبريد بدرجة حرارة ثابتة - منخفضة (21 درجة مئوية) يوفر تبريدًا ممتازًا للوحدة الكهروضوئية ، مقارنةً بالوحدة الكهروضوئية غير المبردة ، وبمقدار 6 درجات مئوية في الساعة 7:00 صباحًا وزيادة لتصل إلى 22 درجة مئوية الساعة 1:00 مساءً. أدى هذا الانخفاض في درجة الحرارة إلى زيادة متوسط في الكفاءة الكهربائية بنسبة 16.7٪. تتراوح الكفاءة الحرارية من 14٪ في الساعة 7:00 صباحًا إلى 58٪ الساعة 2:30 مساءً.

الاستنتاج: تشير النتائج إلى أن هذا النهج فعال في استخدام ورفع كفاءة الطاقة خلال فصل الصيف.

مفاتيح الكلمات: المياه الجوفية؛ PV / T؛ تأثير التبريد؛ أداء؛ بغداد، العراق.