PORT SAID ENGINEERING RESEARCH JOURNAL
Faculty of Engineering - Port Said University
Volume 29 No. 2 pp: 106:113

EXPERIMENTAL STUDY TO IMPROVE THE PERFORMANCE OF SOLAR CELL USING EVAPORATIVE COOLING SYSTEM

Mostafa Baraka[1], Ashraf I. Sayed[2], Ezz Eldeen Salah Elmenyawy[3]*

[1] *Mechanical Power Department, Faculty of Engineering, Al -Azhar University, Cairo, Egypt, email: mostafa_azhar2015@yahoo.com*

[2] *Mechanical Power Department, Faculty of Engineering, Ahram Canadian University, Giza, Egypt, email: ashraf.elsayed@acu.edu.eg*

[3] Ph-D student, Mechanical Power Department, Faculty of Engineering, Al -Azhar University, Cairo, Egypt.

**Corresponding author,* *DOI: 10.21608/pserj.2025.318550.1365.*

Received 5-9-2024
Revised 28-12-2024
Accepted 2-1-2025

ABSTRACT

Environmental degradation has necessitated the advancement of renewable energy, particularly solar energy, which is characterized by relatively low efficiency. The performance of photovoltaic (PV) panels is significantly affected by various factors, including the increase in surface temperature. Employing cooling techniques presents a viable solution to enhance PV performance. This study evaluates the effect of an evaporative cooling system on the performance of PV panels across four seasons. The system incorporates a honeycomb carton pad attached to the underside of one of two mono-crystalline silicon 100 W solar panels, with water supplied to facilitate cooling through evaporation. The other PV panel, without cooling, served as a control. Experiments were conducted daily from 8:00 AM to 4:30 PM. Data were collected on module temperature, ambient temperature, solar irradiance, relative humidity, current, and voltage, with electric power and efficiency calculated accordingly. Results indicated a marked improvement in efficiency and power output for the cooled PV panel, particularly in hot weather conditions. The increase in power output reached 9.41% in June and 5.6% in March, with corresponding efficiency improvements of 9.42% and 5.84%, respectively. During winter and autumn, these improvements were more modest, at 2.6% and 2.8%. The evaporative cooling system offers an economical and effective means to enhance PV panel performance in hot climates.

Keywords: PV panel, Electric Power, Efficiency, Evaporative Cooling System.

1 INTRODUCTION

Environmental degradation, driven by excessive reliance on fossil fuels, represents a critical challenge to global sustainability. Renewable energy sources derived from abundant natural resources with minimal environmental impact, present a viable alternative. However, renewable energy systems, such as those utilizing solar and wind energy, face challenges, including high initial costs and limited efficiency. The efficiency of PV panels, in particular, is adversely impacted by elevated operating temperatures. Kumar, et al. [1] stated that every 1 °C rise in temperature of PV panel leads to decrease of 0.5% in its electric efficiency, but Du D, et al. [2] reported that the Efficiency of PV panel drops by 0.45% for each 1℃ increase. In Cairo, Egypt, it was found that the operating panel temperature could reach 68℃ in summer. This very high temperature was negatively influencing in PV panel output Power, efficiency and life span as J. Zeitouny et al. reported [3].

The energy yield of PV panel depends on a large number of factors such as the amount of solar irradiance strikes the PV panel, which in turn depends on the local climatic conditions (e.g., relative humidity, fixed or tracking system of panels, inclination angle, surrounding buildings, wind speed, dust, etc.) [4] play a significant role. Higher wind speeds lead to lower relative humidity, which improves the efficiency of PV panels. However, increased dust deposition on PV panels reduces their performance [5]. However, when relative humidity rises, the performance of the PV panel (current, voltage, and electric power) decreases. Egypt is located in a semi-arid zone where the sun shines for more than 300 days per year, making it suitable for solar parks. The government has built the Benban Plant, one of the largest solar parks in the world, in Aswan, southern Egypt.

The PV panel converts some solar energy into electric power and some into heat. This heat reduces the panel's electric efficiency, leads to heat losses, energy waste, degradation of panel materials, and increases costs. Cooling the PV panel and removing dust can help address these issues [6]. Maintaining the PV panel temperature below 30 °C can prevent losses of about 5 volts in open-circuit voltage and reduce total yearly degradation in electric efficiency by approximately 10% under normal operating conditions [7]. One noteworthy aspect of photovoltaic (PV) technology is its limited electrical efficiency, which typically does not surpass 20% even under ideal operating conditions. Moreover, this efficiency gradually declines over time due to material degradation and other environmental factors [8].

Improving the performance of photovoltaic (PV) panels through various cooling techniques has been extensively studied by many researchers, aiming to enhance their efficiency and energy output. One common method is cooling by natural air, which helps reduce the temperature of the PV panel by approximately 4°C. This cooling effect results in better efficiency and output performance under warmer conditions [9]. Another technique is cooling by active and passive air systems, where warmed air generated during the cooling process is directed to heat nearby buildings, offering a dual benefit by improving panel performance and providing heating for building spaces [10]. Cooling with ducts and natural blowers is also widely explored, in which an array of ducts is attached to the back of the PV panel. These ducts channel airflow using a natural blower, helping to cool the panel while also enhancing its output power by approximately 12-14%. However, this technique does have a drawback as it consumes a portion of the electricity generated by the PV system itself [11]. Phase Change Material (PCM) is another innovative approach, where materials such as paraffin wax are used to absorb excess heat from the PV panels. This method reduces the temperature of the panel from 78°C to 62°C, leading to a significant increase in output power by up to 55%. PCM offers a promising solution for mitigating the overheating of panels and improving overall system performance [12]. Lastly, thermoelectric cooling (TE) is a hybrid approach that uses some of the electricity produced by the PV panels to actively cool them. This method has been shown to increase the panel's efficiency, improving it from an average of 8.35% to 12.26%, by leveraging the electricity it generates for self-cooling, thus enhancing the energy conversion efficiency of the system [13]. Each of these cooling methods offers unique advantages and challenges, with ongoing research focusing on optimizing their effectiveness to achieve higher energy outputs and overall system efficiency.

Cooling PV panels with water is a simple and cost-effective method. Various water-based cooling techniques include flowing water beneath or over the PV panel to increase power output by approximately 8-9% [14], submerging the panel in water [15], spraying water onto the panel [16], or using evaporation to dissipate heat from the panel [17]. Each of these techniques helps reduce the temperature of the panel, improving its overall efficiency and energy generation.

Increasing the efficiency of PV panels can also be achieved by enhancing the intensity of incoming radiation using concentrators, lenses, or tracking systems. However, this leads to an increase in the PV panel temperature beyond the operating limits, reducing panel efficiency and potentially causing damage due to overheating. Therefore, PV panels perform more efficiently when exposed to cooling techniques, particularly during hot weather [18]. Accumulation of dust on the surface of PV panel could produce a 30% reduction in PV panel efficiency. However, a high temperature can cause a 10% decrease in efficiency [19]. Hachicha et al. [20] used front cooling, back cooling, and a combined (double) cooling method for PV panels by spraying water on them. The results showed that front cooling was the most effective, along with dust removal.

Shaaban et al. [21] reviewed, studied, and evaluated various cooling techniques commonly used for PV panels, including active cooling, passive cooling, and hybrid cooling techniques. They stated that, depending on the type of solar panels and environmental conditions, a typical PV panel converts 6-20% of incoming solar irradiance into electric power, with the remaining irradiance being converted into heat. This heat raises the PV panel's temperature, which in turn reduces its efficiency.

Kemal et al. [22] developed a comprehensive review study on cooling techniques for PV panels used in previous research, analyzing the temperature decrease and enhancement in electrical efficiency for each technique. The study also examined both passive and active cooling techniques, as discussed in earlier theoretical and experimental studies. They found that the most preferred panel type was the polycrystalline panel, the most commonly used cooling technique was active cooling, and the most preferred coolant fluid was water. Figure (1) shows a block diagram of the most common types of PV cooling techniques.

This study aims to optimize PV panel efficiency using an evaporative cooling system. The approach involves integrating a honeycomb cooling pad wetted with a controlled water flow to reduce surface temperatures. Comparative analysis with a control panel under identical conditions evaluates the system's effectiveness across seasonal variations.

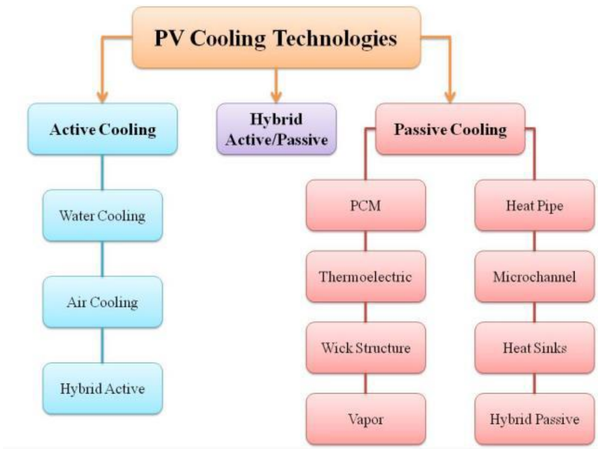

Figure 1: The most common types of PV Cooling Techniques. [21]

2 EXPERMINTAL WORK

The study aimed to assess the effectiveness of an evaporative cooling system by comparing the performance of two mono-crystalline solar photovoltaic (PV) panels under identical conditions. Detailed specifications of the panels are provided in Table 1. To ensure consistent and reproducible experimental conditions, measurement devices were carefully selected, calibrated, and installed.

Table 1. Characteristics of Solar PV Panel.

Parameter	Specification
Dimensions (L x W x T)	1200 x 640 x 30 mm
Voltage at Max. Power (Vmax)	18.00 V
Open Circuit Voltage (V_oc)	2200 V
Current at Max. Power (I_max)	5.5 A
Short Circuit Current (I_sc)	6.05 A
Max. Power (P_max)	100 Watts
PV Panel Type	Mono Crystalline

In the experimental setup, two PV panels were installed at a 30° inclination relative to the horizontal plane. One panel was integrated with an evaporative cooling system, while the other functioned as a control for comparison purposes. Measurement devices were connected to each PV panel to monitor performance metrics. The experimental design ensures that both PV panels are subjected to identical environmental conditions, with the only variable being the presence of the cooling system on one panel. The inclination angle of 30° is a common setting for PV panels, as it approximates the optimal angle for maximizing solar irradiance capture in many geographic locations. Maintaining this standard angle ensures that the results are applicable to typical PV installations.

The careful selection, calibration, and installation of measurement devices are crucial for obtaining accurate and reliable data. Consistent monitoring of parameters such as voltage, current, and temperature enables a comprehensive analysis of the cooling system's effectiveness.

Overall, this study contributes to the ongoing research into methods for enhancing PV panel efficiency through temperature regulation. The findings could have practical implications for improving the performance and longevity of solar PV installations. The two panels are shown in Figures (2), (3), and (4).

Figure 2: Face of two PV panels with 30° angle of inclination with horizontal, one with cooling system and the other without cooling system.

Figure 3: Back of the two PV panels.

Figure 4: Close back to PV panel with Cooling Pad.

2.1 Measuring Devices

In this study, each photovoltaic (PV) panel was equipped with four temperature sensors, two for monitoring surface temperatures and two for recording ambient temperatures. The sensors were strategically positioned at the center of the upper half and the center of the lower half of each PV panel to accurately capture average surface temperatures. Additionally, an extra sensor was employed to measure the temperature of the water prior to its entry into the cooling system.

All temperature measurements were obtained using digital thermometers with a temperature range of -50°C to +200°C and an accuracy of ±2°C. These specifications are consistent with standard digital thermometers used in laboratory settings.

A Pyranometer, specifically a "Solar Power Meter," was employed to measure solar irradiance in watts per square meter (W/m^2). This device featured a 3½-digit display capable of 2000 readings and operated within a range of up to 2000 W/m^2 or 634 $BTU/(ft^2 \cdot h)$. Its accuracy was typically within ±10 W/m^2 (±3 $BTU/(ft^2 \cdot h)$) or ±5%, whichever was greater, under sunlight conditions, with an additional temperature-induced error of ±0.38 $W/m^2/°C$ (±0.12 $BTU/(ft^2 \cdot h)/°C$) from 25°C. The angular accuracy was cosine-corrected to less than 5% for angles below 60°, and the device exhibited a drift of less than ±2% per year. It indicated over-input by displaying "OL" and had a sampling time of 0.25 seconds. The operating temperature and humidity range was 0°C to 50°C with relative humidity below 80%. These specifications align with standard Pyranometers used in solar energy applications.

The Extech CO250 Portable Indoor Air Quality CO_2 Meter was utilized to measure environmental parameters, including temperature, humidity, dew point, and wet bulb temperature. This device offers a temperature measurement range from -10°C to +60°C (14°F to 140°F) with an accuracy of ±0.6°C (±0.9°F). It also measures humidity across a range of 0.0% to 99.9% with an accuracy of ±3%. These specifications are consistent with standard portable indoor air quality meters used in environmental monitoring.

A charge controller was employed to regulate and manage the electrical output from each photovoltaic (PV) panel. Its primary functions included measuring the output voltage and current to calculate the output power, ensuring efficient energy management and protecting batteries from overcharging or deep discharging. By continuously monitoring these parameters, the charge controller optimized the charging process, maintained battery health and enhanced the overall performance of the solar power system.

The water cycle for the cooling pad operates by supplying water at a minimal flow rate to ensure the pad remains adequately moistened. Excess water is collected and recirculated, promoting efficient water usage and maintaining optimal cooling performance.

Fig. 5: Water Cycle for Cooling Pad.

1: Feeding Reservoir for Water.
2: Collecting Reservoir for Excessive Water.

2.2. Experiment Set Up

A cooling pad designed in the shape of a honeycomb and constructed from a special type of cardboard, is capable of absorbing a substantial amount of water, which it then gradually evaporates over a prolonged period. This cooling pad was carefully attached to the rear surface of a photovoltaic (PV) panel to enhance the cooling process. Water was delivered to the pad via a PVC tube, which was connected to a reservoir that was fed by a water entry nozzle. The excess water, after passing through the cooling pad, was collected in a measuring jar to track the flow rate, which was recorded to be approximately 0.03 liters per minute, as illustrated in Figures 4 and 5. The cooling pad positioned at the rear of the PV panel was integral to the operation of the evaporative cooling system. The system works by dispersing water throughout the pad, where it evaporates slowly, thus lowering the temperature of the pad. This temperature drop is then transferred to the attached PV panel effectively cooling it and improving its efficiency. The design of the system relies on the principles of evaporative cooling, where the latent heat of evaporation facilitates heat loss, leading to a reduction in the temperature of both the cooling pad and the PV panel.

The experiments were carried out every day for duration of eight hours, beginning at 8:00 AM and concluding at 4:00 PM. This experimental protocol was consistently followed six days a week across all four seasons throughout the entire year, from January to December 2022. Throughout this period, data from the various measuring devices were systematically collected and carefully recorded for further analysis. The research was conducted at Ahram Canadian University, which is situated in 6th of October City and located within the Giza Governorate in Egypt. The geographical coordinates of the university are 29.93528°N in latitude and 30.88278°E in longitude, positioning the site in a region with specific climatic and environmental conditions that were crucial for the experimental setup. The data gathered during these experiments provided a comprehensive set of measurements, which were used to assess the performance of the cooling system under varying conditions throughout the year.

3 RESULTS AND DISCUSSION

Experiments were carried out, and data were gathered on module temperature, ambient temperature, solar irradiance, relative humidity, current, and voltage for each trial. During each experiment, water evaporated from the cooling pad into the surrounding air, which led to an increase in its relative humidity. Simultaneously sensible heat was transferred from the air to the water while latent heat was transferred from the water to the air. As heat was removed from the PV panel by the cooling pad the ambient temperature dropped and the absolute humidity of the air increased due to the addition of latent heat and the cooling process. When the air had low relative humidity, evaporation occurred more rapidly, and the interaction between the water and air was enhanced promoting more effective cooling.

The collected data were categorized into three groups based on the season, one for summer, one for spring and autumn (since their weather conditions are similar in Egypt), and one for winter. Where the weather conditions were consistent within each category and the results were comparable. Three specific samples were selected to represent the experimental work, one from June for the summer season, one from March for the spring and autumn seasons, and one from December for the winter season. All three samples were gathered on clear sunny days.

The variations in PV module temperature, ambient temperature, and solar irradiance during the sunny hours in June, March and December are presented in the three charts shown in Figures (6), (7), and (8). The recorded temperatures reached their maximum values during the summer and autumn seasons, relative to the average NOCT (Nominal Operating Cell Temperature) for PV modules. Temperatures reached up to 54 °C in March and 70 °C in June. These extremely high temperatures caused a significant decrease in the output voltage and power from the PV panel. During winter, high temperatures caused by maximum irradiance under clear skies kept PV panel temperatures close to the average NOCT. The water flow rate through the cooling honeycomb pad was measured by filling the upper tank with a specific amount of water and calculating the amount of water collected in the lower tank over a certain period. The flow rate was approximately 0.03 liters per minute. This very low flow rate did not consume any electric power.

From these charts, it is clear that module temperature, ambient temperature, and solar irradiance changed together. Module temperatures were generally lower than ambient temperatures except during the early hours of the morning when the PV panel was colder than the surrounding air due to the cooling effect of the night. The difference between module and ambient temperatures due to the cooling system increased especially during the hotter hours and could reach 20 °C or more. The cooling system worked effectively when the weather became hot.

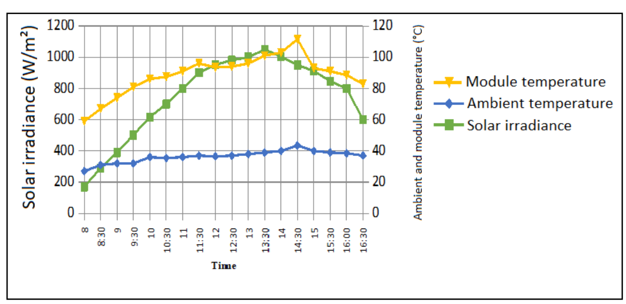

Fig.6: The variation of PV module temperatures, ambient temperatures, and solar irradiance during a clear, sunny day in June.

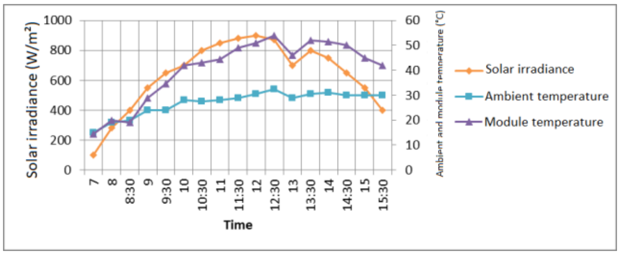

Fig.7: The variation of PV Module temperatures, ambient temperatures and solar irradiance during a clear sunny day hours in March.

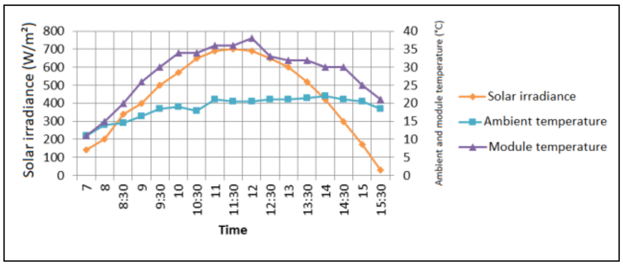

Fig.8: The variation of PV Module temperatures, ambient temperatures and solar irradiance during a clear sunny day hour in December.

For each experiment Voltage (Vmp) and Current (Imp) produced from the PV Panel were measured in two cases (with and without cooling) and Power was calculated from equation (1).

$$Pmp = Vmp * Imp \quad \text{(Watt)} \qquad (1)$$

and Efficiency was calculated from equation (2)

$$Efficiency(\eta)=(Vmp*Imp)/(G*A) \qquad (2)$$

For all experiments, the developed voltage, power and efficiency with cooling system were higher than without cooling system but the increments varied from season to another. In June maximum power was gained at noon (12:30) from PV panel with cooling system was (103.29 W), where the maximum increment in power was (9.41 %) at (11:00) and maximum efficiency occurred at early morning (8:00) was (44.85 %) with increment (1.65 %), whereas the maximum increment in Efficiency was (9.42 %) at (11:00).

In March, the maximum power from the PV panel with the cooling system was achieved at noon, specifically at 13:30, reaching 85.7 W. The highest power increment, which was 5.6%, occurred at 11:00. The maximum efficiency was observed early in the morning, at 8:00, with a value of 74.2% and an increment of 1.45%. Meanwhile, the highest increment in efficiency, 5.8%, was recorded at 11:00.).

In December, maximum power was gained at noon at (12:30). It was (74.1 W) from PV panel with Cooling System, where the maximum increment in power was (2.63 %) at (12:30) and maximum efficiency occurred at early morning also at (8:00) was (55.6 %) with increment (1.93 %), whereas the maximum increment in efficiency was (2.78 %) at (12:30). For example, figure (9) shows the power Gained from PV panel with and without Cooling System and the increment occurred in power gained during June.

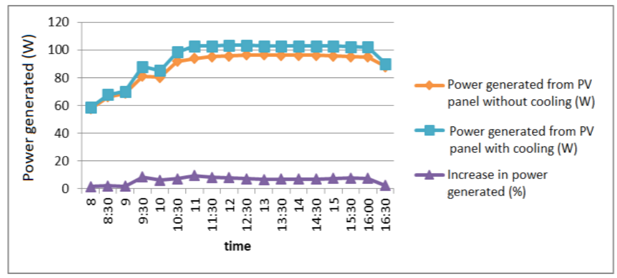

Fig.9: The increment in power generated from two PV panels during June.

The efficiency of PV panel with cooling system was almost higher than without cooling system as shown in figure (10), where the efficiency of both panels decreased when solar irradiance increased and weather became hot as shown.

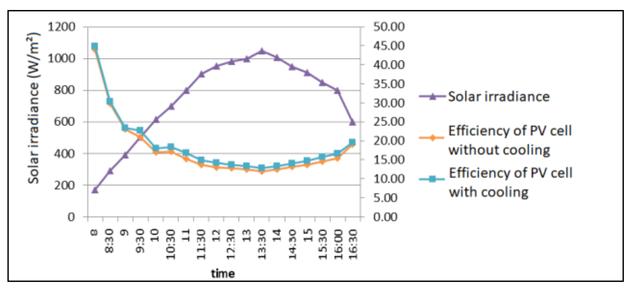

Fig.10: The efficiency of two PV panels during the experiment in June.

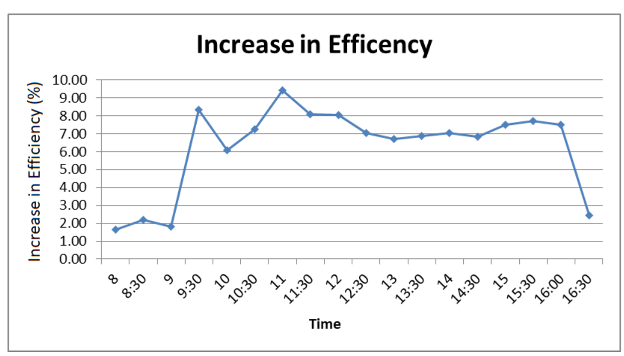

Fig.11: The increment in efficiency of PV panel with cooling system in June.

The evaporative cooling system significantly reduced ambient temperatures in all experiments, with the extent of the reduction depending on the weather conditions. The efficiency of the PV panel was improved by a range of 1.65% to 9.42% in June, 1.25% to 5.84% in March, and 0.62% to 2.77% in December. This led to an increase in the power generated by the PV module, which ranged from 1.67% to 9.41% in June, 1.2% to 5.6% in March, and 0.54% to 2.63% in December. The evaporative cooling System with the honeycomb pad proved to be particularly effective in hot weather.

4 CONCLUSION

The efficiency of solar energy systems is inherently limited, and their performance is significantly impacted by the rise in PV panel surface temperatures, which reduces output power, electrical efficiency, performance, and longevity. This study demonstrated that evaporative cooling achieved by integrating a carton honeycomb pad beneath the PV panel and injecting water effectively reduces surface temperatures without consuming electrical power. The cooling system was tested over a full year (2022) by comparing two PV panels—one equipped with the cooling system and one without—under identical conditions.

The results showed that module temperatures consistently exceeded ambient temperatures even in colder seasons. The PV panel equipped with the evaporative cooling system demonstrated improved performance compared to the panel without cooling. The most notable improvements were observed during summer (June) with a 9.41% increase in generated power and a 9.42% increase in electrical efficiency. Similar gains were recorded in spring (March) and autumn while the winter season showed modest improvements (2.6% in power and 2.8% in efficiency).

While the study did not aim to achieve the theoretical optimum efficiency of PV panels, it demonstrated that the proposed evaporative cooling system is a practical and effective approach to mitigating temperature-related efficiency losses, particularly in hot climates. These findings align with previous studies, such as Hachicha et al. [20], which showed performance improvements with water-based cooling methods but with power consumption trade-offs. In contrast, this system required minimal water use and no additional electrical power making it cost-effective and sustainable for applications in Egypt's climate.

In conclusion, the proposed evaporative cooling system is a viable and sustainable method for improving PV panel performance in hot climates, with minimal operational costs and no energy trade-offs. Future research could explore optimizing this system for varying climatic conditions and integrating it with other renewable energy strategies.

5 LIST OF ABBREVIATIONS

Imp	**: Current at max power**
Isc	**: Short circuit current**
P max	**: Maximum power**
NOCT	**: National Operating Panel Temperature**
PCM	**: Phase Chang Material**
PV	**: Photo voltaic**
TE	**: Thermoelectric cooling**
V mp	**: Voltage at Max Power**
Voc	**: Open Circuit Voltage**
Vom	**: Volt-Ohm-milliammeter**
G	**: Solar irradiance (measured in watts per square meter, W/m²).**
A	**: The area of the photovoltaic (PV) panel (measured in square meters, m²).**

Credit Authorship Contribution Statement:

EzzElden Salah Elmenyawy: Methodology, Writing Original Draft, Software and Experiments.
Dr. Ashraf Sayed: Conceptualization, Review and Editing, Supervision.
Prof. Mostafa Ali Mohamed: Supervision, Review and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

6 REFERENCES

[1] K. Kumar, S. Sharma, L. Jain and R. Al Khaimah, Standalone Photovoltaic (PV) module outdoor testing facility for UAE climate. Submitted to CSEM-UAE Innovation Center LLC , 2007.
[2] Du D, Darkwa J, Kokogiannakis G. Thermal management systems for Photovoltaics (PV) installations: a critical review. Sol Energy 2013;97:238–54.
[3] J. Zeitouny, N. Lalau, J.M. Gordon, E. A. Katz, G. Flamant, A. Dollet, and A. Vossier, Assessing high-temperature photovoltaic performance for solar hybrid power plants. Solar Energy Materials and Solar Panels, 2018, Vol. 182, 61-67.
[4] H.A. Kazem, and M.T. Chaichan. Effect of Humidity on Photovoltaic Performance Based on Experimental Study. International Journal of Applied Engineering Research, 2015, Volume 10, Number 23 pp 43572-43577. http://www.ripublication.com.
[5] S. Mekhilef, R. Saidur and M. Kamalisarvestani. Effect of dust, humidity and air velocity on efficiency of photovoltaic panels, Renewable and Sustainable energy Reviews, vol. 16, pp: 2920-2925,2012.

[6] Z.A. Haidar, J. Orfi and Z. Kaneesamkandi. Experimental investigation of Evaporative Cooling for enhancing photovoltaic panels efficiency. Results in Physics, 11, 2018, 690–697.
[7] J. Siecker, K. Kusakana and B.P.A. Numbi. A review of solar photovoltaic systems cooling technologies: Renewable and Sustainable. Energy Reviews, 2017, 79, 192-203.
[8] F. Mossayebi. Finite element analysis of heat conduction in the absorber plate of a solar collector. Master of Science in Engineering in the Mechanical Engineering, Youngstown State University, 1987.
[9] Edenburn, M. "Active and passive cooling for concentrating photovoltaic array" Sandia Labs., Albuquerque, NM (USA);1980.
[10] Mei L, Infield D, Eicker U, Fux V. Thermal modelling of a building with an integrated ventilated PV façade. Energy Build 2003;35:605–17.
[11] Teo H, Lee P, Hawlader M. An active cooling system for photovoltaic modules. Appl Energy 2012;90:309–15.
[12] Maiti S, Banerjee S, Vyas K, Patel P, Ghosh PK. Self-regulation of photovoltaic module temperature in V-trough using a metal–wax composite phase change matrix. Sol Energy 2011;85:1805–16.
[13] Borkar DS, Prayagi SV, Gotmare J. Performance evaluation of photovoltaic solar panel using thermoelectric cooling. Int J Eng Res 2014;3:536–9.
[14] Krauter S. Increased electrical yield via water flow over the front of photovoltaic panels. Sol Energy Mater Sol Panels 2004;82:131–7.
[15] Krauter, S. "Thermal and optical enhanced PV-modules". In: Proceedings of the 13th European Photovoltaic Solar Energy Conference; 1995, pp. 2306-9.
[16] Moharram KA, Abd-Elhady M, Kandil H, El-Sherif H. Enhancing the performance of photovoltaic panels by water cooling. Ain Shams Eng J 2013;4:869–77.
[17] Alami AH. Effects of Evaporative Cooling on efficiency of photovoltaic modules. Energy Convers Manage 2014;77:668–79.
[18] E. El-Shazly, A.A. Abed-Rehim, A. Abdel-Kader and I. El-Mahallawi. Effect of Dust and High Temperature on Photovoltaics Performance in the New Capital Area. WSEAS TRANSACTIONS on ENVIRONMENT and DEVELOPMENT. DOI:10.37394/232015.2021.17.36.
[19] E El-Shazly, A. Abd El-Rehim and I. El-Mahallawi, I. Comparison of dust and high- temperature effects on mono and poly photovoltaic panels. IOP Conf. Series: Materials Science and Engineering. 1172, 2021 012019. doi:10.1088/1757-899X/1172/1/012019.
[20] A.A. Hachicha, C. Ghenai and A. Hamid. Enhancing the Performance of a Photovoltaic Module Using Different Cooling Methods. World Academy of Science, Engineering and Technology. International Journal of Environmental, Chemical, Ecological, Geological and Geophysical Engineering Vol:9, No:9, ,2015, scholar.waset.org/1999.6/10002519.
[21] A. Shaaban, M. Mosa, A. El-Samahy, and K. Abed. Enhancing the Performance of Photovoltaic Panels by Cooling: a Review. International Review of Automatic Control (I.RE.A.CO.), Vol. 16, N.1, ISSN1974-6059, January 2023.
[22] Kemal Bilen and İsmail Erdoğan. Effects of cooling on performance of photovoltaic/thermal (PV/T) solar panels: A comprehensive review. Solar Energy. ELSAVIER, Vol.262, 15 September 2023, 111829.
[23] P. Dwivedi, K. Sudhakar, A. Soni, E. Solomin, I. Kirpichnikova. Advanced cooling techniques of PV modules: A state of art. Case Studies in Thermal Engineering,21,,2020,100674:1-17.
http://www.elsevier.com/locate/csite.
[24] H. Bahaidarah, A. Subhan, P. Gandhidasan and S.Rehman. Performance evaluation of a PV (photovoltaic) module by back surface water cooling for hot climatic conditions. Energy, 2013, 59, 445–453. http://dx.doi.org/10.1016/j.energy. 2013.07.050.
[25] K.A. Moharram, M.S. Abd-Elhady, H.A. Kandil .and H. El-Sherif. Enhancing the performance of photovoltaic panels by water cooling. Ain-Shams Eng. J., 2013, 4 (4),
869–877. http://dx.doi.org/10.1016/j.asej.2013.03.005.