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Article

Fin orientation effect on passive cooling of photovoltaic panels: an experimental study under extreme hot climate

Dheyaa S. J. Al-Saedi[1], Hayder Al-Lami[1], Mushtaq A. Al-Furaiji[1], Rasha Abed Hussein[2], Qudama Al-Yasiri[1]*

[1]College of Engineering, University of Misan, Al Amarah City, 62001, Iraq
[2]Department of Dentistry, Al-Manara College for Medical Sciences, Maysan, Iraq

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*Corresponding author
Email address:
qudamaalyasiri@uomisan.edu.iq

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ABSTRACT

Solar photovoltaic (PV) panels are a fast-growing solar technology worldwide. However, the PV efficiency is still limited, especially in hot locations due to increased operating temperature. In this research, a PV panel cooled using L-shaped aluminium fins attached passively in various orientations was tested and analyzed compared with another conventional PV under hot Iraqi weather conditions. The average surface temperature reduction, power output augmentation, and electrical efficiency improvement were analyzed and discussed. The research outcomes exhibited positive thermal advancements for the modified PV regardless of fin orientation, with superior performance for the random arrangement. The PV maximum average surface temperature was reduced by 6.5 °C for the random fin arrangement, utilizing the vortices generated from various fin directions. The power output of the modified PV panel was improved over the conventional one by up to 6.54, 10, and 17 W for the vertical, horizontal, and random arrangements, respectively. Besides, the electrical efficiency of the PV with random fin orientation was augmented by 8.6 %, 13.7 % and 23.1 % compared to the vertical, horizontal, and base PVs.

1. Introduction

Solar energy has the potential to substitute traditional energy sources for its safe operation, environmental friendliness, sustainability, and reliability [1]. Among solar systems, photovoltaic (PV) panels were commonly used to produce electric power by transforming sunlight into electricity. These systems have been practiced in numerous residential and commercial applications for small and medium levels, showing potential in electric power production [2]. Besides, some large-scale PV plants have been installed in some spots of the world to supply electricity on a national level. However, PVs are facing serious concerns, including decreased efficiency at high operation temperatures, poor performance, and shortened lifespan in hot locations. Consequently, some cooling tendencies were investigated to reduce the PV temperature and augment its efficiency, employing active cooling fluids (namely air, water, and nanofluids) on the PV front or rear sides [3]. Nevertheless, passive techniques were also explored, including the use of extended surfaces (fins) [4], baffles [5], turbulators [6], roughness [7], porous media [8], tracking [9], phase change materials [10], and so on [11], showing positive advancements with cost-effectiveness. The research in PV cooling is increasing year by year, exploring new cooling techniques that have shown notable advances in this regard. Figure 1 displays the progress of research efforts in this domain according to Scopus database statistics. The implementation of fins as a passive cooling technique for PV panels is among the most investigated techniques, as a sole or emerging method with other enhancers. Metal fins have shown notable research efforts over the last years due to their ease of installation, flexibility, availability, cheap manufacturing process, and possible application for solar PV plants [12]. Madhi et al. [13], for instance, conducted a numerical study to evaluate the impact of various fin configurations on the efficiency of PV panels. They examined a series of cooling modules, incorporating fin turbulators within a serpentine channel installed on the sides of a PV panel to enhance its efficiency. Four fin angles (30°, 45°, 60°, and 90°) were employed under water-based laminar flow conditions as the cooling fluid. The importance of fin configuration and Reynolds number of fluid flow was identified in a serpentine channel to enhance thermal dissipation. The results showed that the 30° fin configuration yielded the best thermal performance while achieving the highest heat transfer coefficient using the 90° fin configuration.

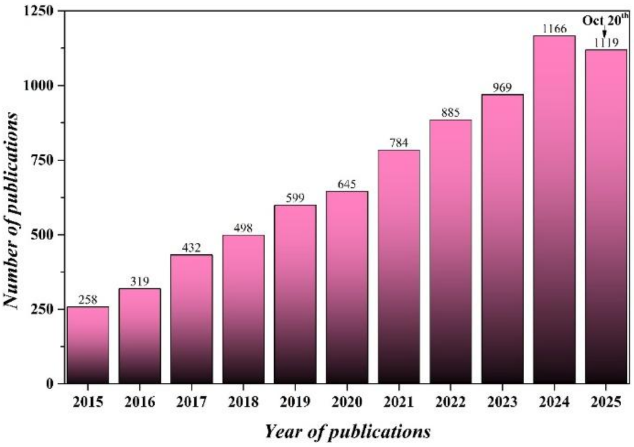

Figure 1. Number of publications by year on the PV cooling, considering the Scopus database (accessed on 20 October 2025, applying "photovoltaic cooling" as keywords).

In addition, the proposed PV system revealed a significant electrical efficiency improvement of 0.8 %- 1.5 % compared to conventional PV. Similarly, Genge et al. [14] numerically studied the role of embossed fins as heat dissipated in enhancing PV module thermal performance using the Computational Fluid Dynamics simulation tool. In their research, different embossed fin shapes, namely triangular, square, circular, and smooth fins, were utilized. In addition, they investigated the underlying mechanisms through which embossed geometries influence fluid flow dynamics and enhance turbulence, thereby improving the efficiency of heat transfer convectively. Research findings demonstrated that the triangle embossed fins have a significant effect in enhancing convective heat transfer efficiency, achieving the lowest average surface temperature for the PV module by about 41.78 °C. Moreover, it was observed that the most irregular and chaotic airflow was achieved by the triangular emboss fin, followed by the square, circular, and smooth fin parts, respectively. Therefore, it was suggested that the triangular emboss fin induced the maximum turbulence compared to the others.

The influence of fin height, fin spacing, number of fins and inlet air speed was systematically investigated by Wang et al. [15]. In their research, they examined the relationship between the effect of fin height, fin spacing, number of installed fins and wind speed on the cooling performance of solar PV system efficiency. Besides, installing aluminium fins on the back side of the PV panel with air-forced circulation using a fan system has been proposed as a cooling technology. The study revealed that increasing fin height with a range between 50 to 80 mm with decreasing fin spacing has a remarkable influence on temperature reduction, thus enhancing power generation efficiency. When the height of the fins was 90 mm and the space of the fins was 6 mm, the PV panel temperature was 61.4 °C. The operation temperature was decreased by 19.6 °C compared to the referenced one without fins, while the power generation and electrical efficiency were improved by 10.09 % and 1.24%, respectively. The findings showed that as air inlet velocity gradually increased to a certain range with various fin heights, the surface panel temperature was reduced gradually. However, after the inlet wind speed of the air channel exceeds 2 m/s, the impact of fin height on the heat exchange performance of the PV panel becomes negligible, and the reduction in the PV panel temperature becomes slower. Cabrera-Escobar et al. [16] conducted research to study the influence of proposed heat-dissipating fins made of copper on the PV conversion efficiency. Various copper fins with heights (namely 20, 40, 60, 80, and 100 mm) were examined. The research concluded that the heat dissipation efficiency of installed copper fins was directly proportional to the fin exposure area, due to increased fin height. The results showed that copper fins with a height of 40 mm exhibited the highest heat dissipation, resulting in a 2.64 K reduction in the PV panel's temperature, leading to a 1.32 % improvement in efficiency. The study concluded that the effectiveness of the copper fins was improved under higher temperature conditions. Hudișteanu et al. [17] implemented research on using an innovative air-cooling technique of copper heat sinks with modified fins (perforated and non-perforated) for enhancing the conversion efficiency of PV panels. In their study, four different models of horizontal heat sinks, incorporating fins with and without perforated and vertical heat sinks, were studied. The results revealed significant efficiency enhancements through all model configurations, with values ranging from 5.28 % to 5.92 %. Perforated fin-heat sinks exhibited a minor enhancement, achieving efficiencies between 5.82 % and 5.92 %, compared to 5.28 % to 5.69 % for their non-perforated fin-heat sinks. It was demonstrated that saving material up to 5 % could be achieved due to perforation, in addition to the superior enhancement of perforated fins-heat sinks. Furthermore, perforated heat sinks have offered greater efficiency enhancements at a reduced cost compared to their non-perforated counterparts. Literature studies have reported notable thermal and electrical advancements in PV panels using fins. However, other studies have shown superior improvements when incorporating fins with other enhancing methods, such as air cooling, water, nanofluids, and PCMs. A summary of recent studies that discussed the cooling potential of fins with other enhancement methods is presented in Table 1.

While the distinctive advantages of using PV systems to generate electrical power and reduce carbon emissions as one of the sustainable resources have been clearly stated in the literature, there are also worries associated with the operation temperature rises and reduced electrical efficiency. Enormous efforts have been invested in developing a vast range of cooling approaches to solve and mitigate these concerns, implementing metal fins as an attractive and cost-effective method to cool PV panels. Literature studies have extensively studied the thermal influence of fin material, fin shapes, number of installed fins, the fins' height, and fins' spacing under passive and active air-fluid flow as cooling media. However, the effect of fin orientation on the performance of PV cooling behaviour has received little attention in recent studies. Therefore, this research aims to experimentally examine the influence of random fin orientation on PV surface temperature reduction, power output production and efficiency improvement compared with uniform orientations. Moreover, simply designed L-shaped aluminium fins have been adopted in this research thanks to their easy construction and potential to enhance thermal performance under hot weather conditions. This research approach is essential to improve the PV system design and encourage the use of cost-effective passive enhancers towards more sustainable renewable systems.

Table 1. Literature contributions on PV panel cooling by fins and diverse cooling methods

Reference	Country	Cooling Technique	Fins design	Performance improvement		
				PV temperature reduction	Electrical efficiency increment	Power output augmentation
[18]	Malaysia	Air-based technique	Multidirectional tpered fin hat snks	12 ^{0}C	1.53 %	-----
[19]	Iran	PV-PCM passive cooling	pin, Y-shaped, and spring fins	9 ^{0}C	4 %	0.8 %
[20]	Egypt	Partially submerged fins (Air/water cooling)	An angle solid fins array (non-perforated fins) and an angle perforating fins array	33.31%	22.77 %	-----
[21]	Algeria	PCM with fins	PCM cooling container with a set of fins of different materials (graphite, copper, steel and titanium)	Using graphite and copper 3^{0}C	Graphite ≈ copper (~11.75 %), Steel ≈ titanium (~11.6–11.7%), and Pure PCM (~11.4–11.65 %)	-----
[22]	Egypt	Partially submerged fins (Air – water-based technique)	partially submerged floating FPV system with fins	19.07 %	24.02 %	22.24 %
[23]	India	Air-based passive cooling	Aluminium-fins integrated photovoltaic module	7%	-----	5.47%
[24]	Turkey	PV-PCM passive cooling	PCM (paraffin) + steel foam mixture and two different angular finned heat sink attachments	-----	Inclined fins 5.09% Flat fins 6.18%	Inclined fins 41.4% Flat fins 59.53%
[25]	Iraq	Air-based cooling	rectangular aluminium fins (RAFs) and evaporative cooling cotton wicks immersed in water (CWWs)	6.7%	-----	21.3%
[26]	Malaysia	Water-based cooling	cooling nano-fluid circulation system with a micro fin tube (inner grooved) encapsulated with nano-PCM	45 ^{0}C	9.6 %	-----
[27]	Algeria	Air-based cooling	skeleton-shaped fins used to create double-pass ambient air channels	-----	8.61 %	11.76 %
[28]	India	Heat sink encapsulated with two different PCMs.	Pin fin configurations, inclusive of triangular, hexagonal, square, and circular, with PCMs	12 ^{0}C – 13 ^{0}C	9 %- 10 %	11 %
[29]	Hungary	Bi-fluid (air and water) with fins	Louvre-shaped fins with a serpentine tube were mounted with a bi-fluids	19.2 ◦C	6.7% for the air-cooled model and 66.17% for the bi-fluid cooled model	13.144 %
[30]	China	Fin–PV/PCM cooling	PCM and fins are added to cool the PV model	31.9 ^{0}C	-----	-----
[31]	UAE	Air-based cooling	A segmented multiangular aluminium fin heat sink	10 ^{0}C	5 %	-----
[32]	Algeria	Active and passive cooling approaches	Three bi-fluid configurations (air and water) PV/T manifolds according to the number of fins	-----	50.54% for hybrid PV/T without fins, 52.33% for hybrid PV/T with 20 fins and 54.25% for hybrid PV/T with 40 fins.	-----
[33]	Dubai	Air-based cooling	Hybrid air-fin heat sink cooling	13.6 °C	-----	4.4 %
[34]	China	PV-PCM with rectangular fins technique	PV-PCM collector with rectangular copper fins,	16.11 °C	11.19%,	-----

2. Materials and methods

2.1 Experimental set-up

Two PV modules were used in this research, one of them modified with L-shaped fins with various orientations, namely vertical (PVv), horizontal (PVh) and random (PVr), and the other, left without fins, represents the base case (PVb). The PV panels were installed with a south orientation and tilt angle of 30°, the optimal tilt angle for Al-Amarah City (located at latitude: 31.85 and longitude: 47.15), Iraq [35]. Figure 2 and Table 2 show the experimental PV modules and their specifications as provided by the manufacturer.

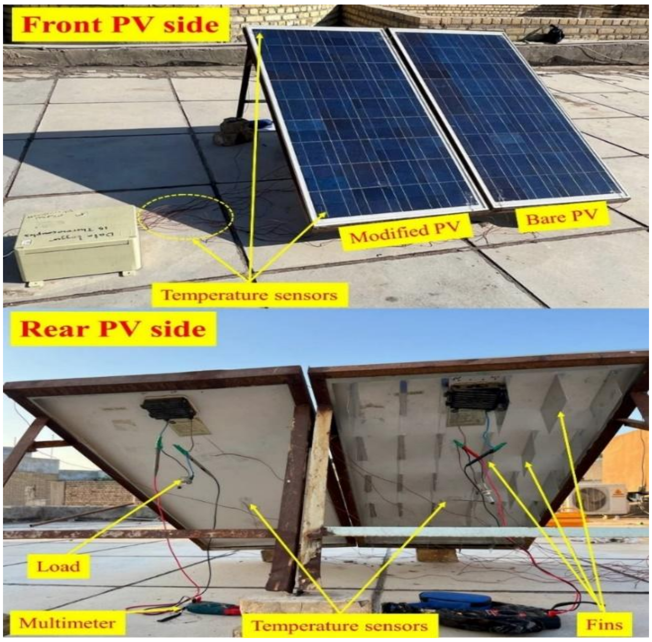

Figure 2. Experimental setup of the test PV modules

Table 2. PV module specifications according to the manufacturer's datasheet [36]

Specification	Value
Module brand	SUNBEAM, Sweden
PV type	polycrystalline
Peak power	110 W
Max. power voltage	17.6 V
Max. power current	6.3 A
Open-circuit voltage	21.6 V
Short-circuit current	6.6 A
Dimensions Length Width Thickness	 1300 mm 680 mm 35 mm
Panel weight	10.6 kg

2.2 Modified PV panel

The modified PV module was delivered with 30 L-shaped fins, distributed on the rear PV module in vertical (PVv), horizontal (PVh) and random (PVr) arrangements (Figure 3). The spaces between fins in the PVv and PVh arrangements were constant, while they were randomly fixed in the PVr arrangement, following no specific pattern. This could simplify the installation process and eliminate the dependency on uncontrolled wind direction throughout the day. The main reason behind this fin design is its simple configuration, cost-effectiveness, and easy production with large quantities. Besides, the availability of waste aluminium sheets in the location under study is another reason to reuse such metals towards waste recyclability and sustainability in existing energy systems. All fins were identical, made of aluminium (1 mm thickness), having a 10 × 15 cm² net area with 1 cm folded from the long side to provide good contact with the PV backside. Fins were fixed on the rear PV side using thermal glue to ensure good thermal contact and heat dissipation from the panel.

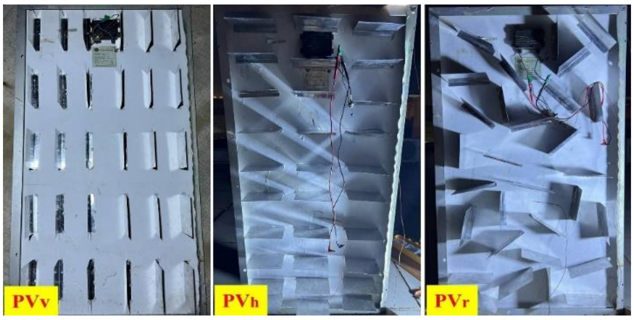

Figure 3. Modified PV panels with various fin orientations

2.3 Measurement devices

T-type temperature sensors were utilized to record the PV surface temperature and ambient temperature variations during the experimental days. In this regard, four sensors were installed on the front PV module side, on the corners, and two were fixed on the backside to quantify the average surface temperatures. Besides, two temperature sensors were employed for the ambient temperature measurement. Temperature sensors were attached to an Arduino (Mega 2560), which was programmed to record temperatures with 30-minute time steps. This data logger was constructed, calibrated, and tested by the well-known electronics company Ardunic in Iraq [37]. The solar radiation throughout the experiments was measured using a handheld solar power meter every 30 minutes, too. In addition, the voltage and current during the working period were measured using two multimeters. Table 3 lists the characteristics of the used devices.

Table 3. Characteristics of measurement devices [38]

Measurement device/ Model	Range	Resolution	Accuracy
Thermocouples T-type (0.2 mm)/ TEMPSENS	-270 °C – 370 °C	-----------	+/- 0.5 °C
Solar power meter/ SM206	1~3999 W/m²	0.1 W/m²	±10 W/m²
Multimeter (voltage, current)/ Sanwa DCM60R	ACA: 199.9/ 600A ACV: 199.9/ 600V	0.1 A 0.1 V	±(2%+5) ±(1.5%+5)

2.4 Assessment of PV modules

The modified PV panels were assessed compared to the base panel, considering the reduction in surface temperature and augmentation of the power output and electrical efficiency. The power output (in Watts) was estimated considering the current (in Amperes) and generated voltage (in volts) for the modified and base PV modules, as mathematically presented in Eq (1).

$$Power = Current \times Voltage \quad (1)$$

Specifying the uncertainty of power output is crucial in this research since it is influenced by the generated current and voltage from the PV panels, and later as input to calculate the electrical efficiency. Therefore, the power uncertainty was calculated by adopting the Coleman and Steele approach, considering the error of measuring the current and voltage as mathematically presented in Eq (2) [39].

$$\frac{\Delta Power}{Power} = \sqrt{\left(\frac{(\Delta Voltage)}{Voltage}\right)^2 + \left(\frac{\Delta Current}{Current}\right)^2} \quad (2)$$

The values of power, current, and voltage in the denominator of Eq (2) represent the values of experimental PV panels delivered by the manufacturer's datasheet. Consequently, the power output uncertainty attained in the analysis was about ±0.03% on average.

The electrical efficiency (in %) of experimental PV panels was estimated considering the power output of the PV modules, incident solar radiation on PV panels (in W/m^2), and the PV module area (in m^2). Mathematically, the electrical efficiency of experimental PV panels was calculated using Eq (3).

$$Electrical\ efficiency = \frac{Power}{Solar\ radiation \times PV\ area} \quad (3)$$

3. Results and discussion

3.1 Location weather conditions analysis

Experimentations were conducted under the weather conditions of Al Amarah City, located in the southeastern region of Iraq, from 23 to 25 September. The weather conditions during the experiment period were comparatively the same, with lower fluctuations in the solar radiation and ambient temperature on the first experimental day. Figure 4 shows the wind speed and direction during the experimental day, collected from a nearby weather station belonging to a governmental Agricultural company. As could be observed in the sub-figures, the wind speed was mostly the same during experimental days, with a value of no more than 6 m/s in the late afternoon. Moreover, the wind direction has also shown the same trend with most West and North-West directions, except for the first day, which showed East and South-East wind at midday.

3.2 Thermal analysis of PV surface temperature

Figure 5 displays the disparity in PV modules' average surface temperatures, ambient temperatures, and solar radiation measured on-site during day hours for all investigated cases. Generally, affixed fins on the rear surface of PV panels have shown notable cooling potential for the modified PVs compared to the base case in all experiments. This behavior is expected since fins enhance the airflow pattern and expand the heat transfer surface, improving the power output and electricity efficiency [40]. As presented in Figure 5, the front and back surface temperatures of the base PV panel were constantly higher than those of the modified PV panel in each case. The highest temperatures recorded on the front surface of the base PV were 58 °C, 64.5 °C, and 66.5 °C for the PV panel modified with vertical, horizontal, and random fins, respectively. On the contrary, lower temperatures were observed on the front surface of the modified PV, with an average of 54.5 °C, 58.5°C, and 60 °C for the vertical, horizontal, and random fin arrangements, respectively. Moreover, the same behavior was observed when comparing the back-surface temperatures of both the base and finned PV, with noticeable differences in each temperature value. This temperature difference is a result of integrating aluminium fins at the back of the PV panel, which greatly enhances heat dissipation, resulting in a steady decrease in front temperature of around 3.5 °C, 6 °C, and 6.5 °C for the studied cases, respectively. The cooling process not only improved the electrical efficiency of the panel but also may prolong its lifetime by mitigating thermal stress. Therefore, adopting fins is a cost-effective and straightforward method for enhancing the energy production and longevity of PV systems, especially in hot regions. Moreover, it was evidenced that the temperature of the PV panel increased as the sunlight irradiation increased. This is due to converting a portion of the solar energy into heat inside the panel, reducing the panel's efficiency, as earlier stated by many literature studies [41].

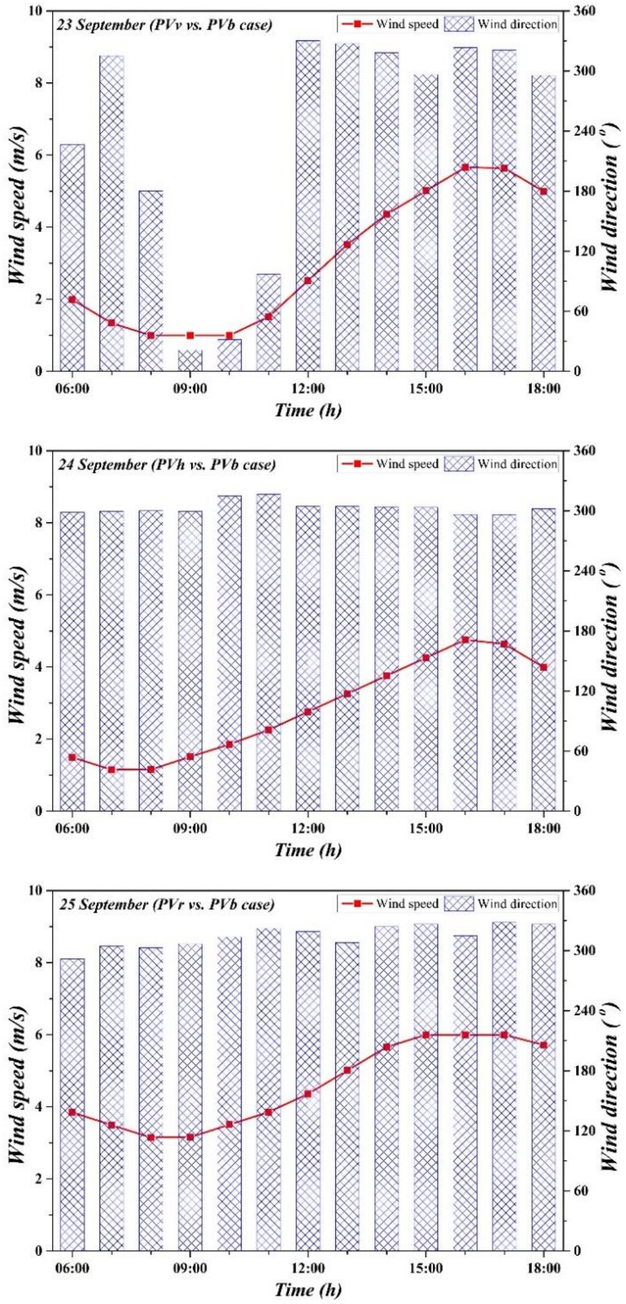

Figure 4. Hourly wind speed and direction in the location under study during experiments

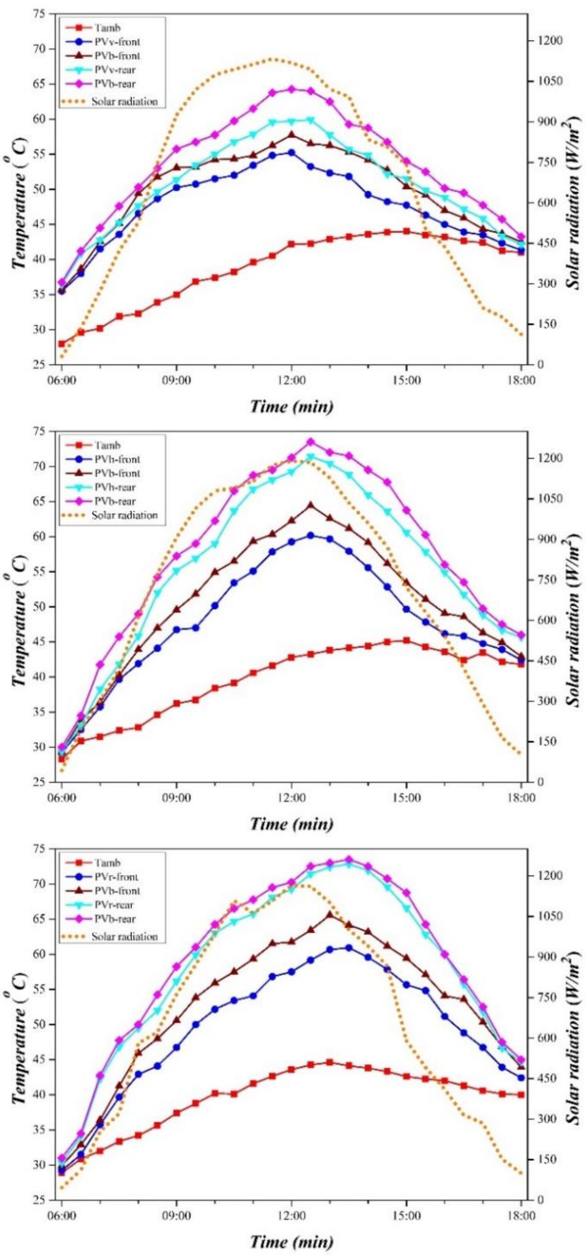

Figure 5. Front and rear surface temperatures, ambient temperature, and solar radiation of PV panels

Additionally, Figure 6 displays thermal images of modified PV modules, illustrating the temperatures of the front and back surfaces compared with those of the base case. The thermal images indicated substantial surface temperature differences between the base and modified PV panels. The thermal photos indicated that integrating fins on PV panels has significantly decreased the surface temperature on both panel sides compared to the base panel. Specifically, Figure 6 displayed that the temperature difference between the front and rear surfaces of the PVb and PVv was reduced by 6.3 °C and 7.8 °C, respectively. Likewise, the front-rear surface temperature was decreased by 9.1 °C and 10 °C in the case of PVb versus PVh, and by 8.6 °C and 11.7 °C in the case of PVb versus PVr. Correspondingly, these values signify temperature reduction by 23.8 %, 9.9 % and 36 % in the modified PV using vertical, horizontal, and random fin arrangements, respectively. Therefore, either random or vertically-arranged fins are more effective in decreasing the PV temperature compared to the horizontally-arranged fins. As a consequence, in all three different fin arrangements, the PV panels have consistently exhibited lower temperatures, indicating superior heat dissipation, enhancing the panel's overall efficiency. Although all fin designs have yielded favorable outcomes, the specific temperature decrease shows minor variations with fin orientation, underscoring the need for optimized thermal management to improve PV performance.

3.3 Electrical performance analysis

The integration of fins on the PV panel's rear surface led to a significant enhancement in current as well as voltage output. The decrease in temperature, attained by improved heat dissipation, directly facilitated this performance enhancement. The fins' cooling action consistently enabled the PV panel to function under more advantageous thermal stability, since elevated temperatures are recognized to diminish the electrical efficiency of PV panels. Figures 7 and Figure 8 depict the variation of current and voltage of PV panels throughout experimental days employing various fin arrangements. The figures demonstrated an enhancement in the PV panel outputs due to utilizing fins, especially during peak solar hours. The current and voltage are slightly elevated when fins are used, in contrast to the base PV panel. Furthermore, the highest current recorded during the experiments for the modified PV panel was 5.29, 5.23, and 5.6 A in the PVv, PVh and PVr, respectively.

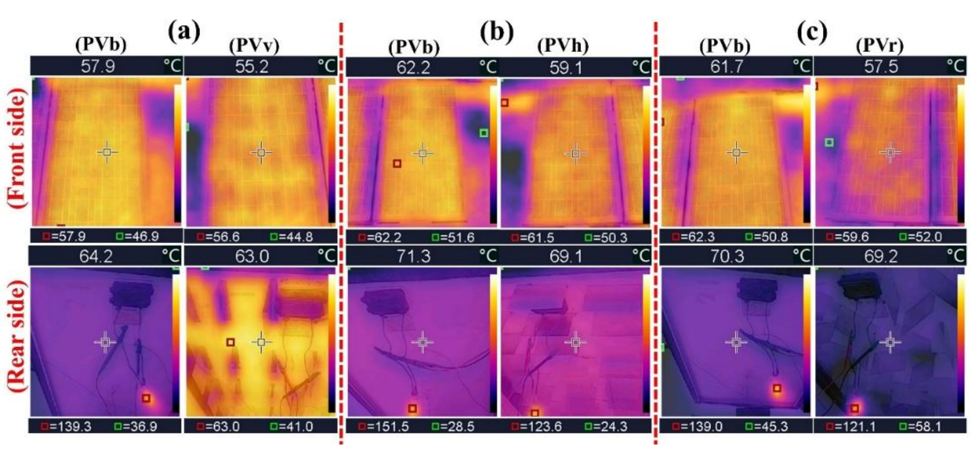

Figure 6. Thermal photos of the front and rear surface temperatures of PV panels (a) PV_b Vs. PVv, (b) PV_b Vs. PVh, (c) PV_b Vs. PVr

Correspondingly, the PV panel without fins exhibited currents of 5, 4.66, and 4.69 A, respectively.

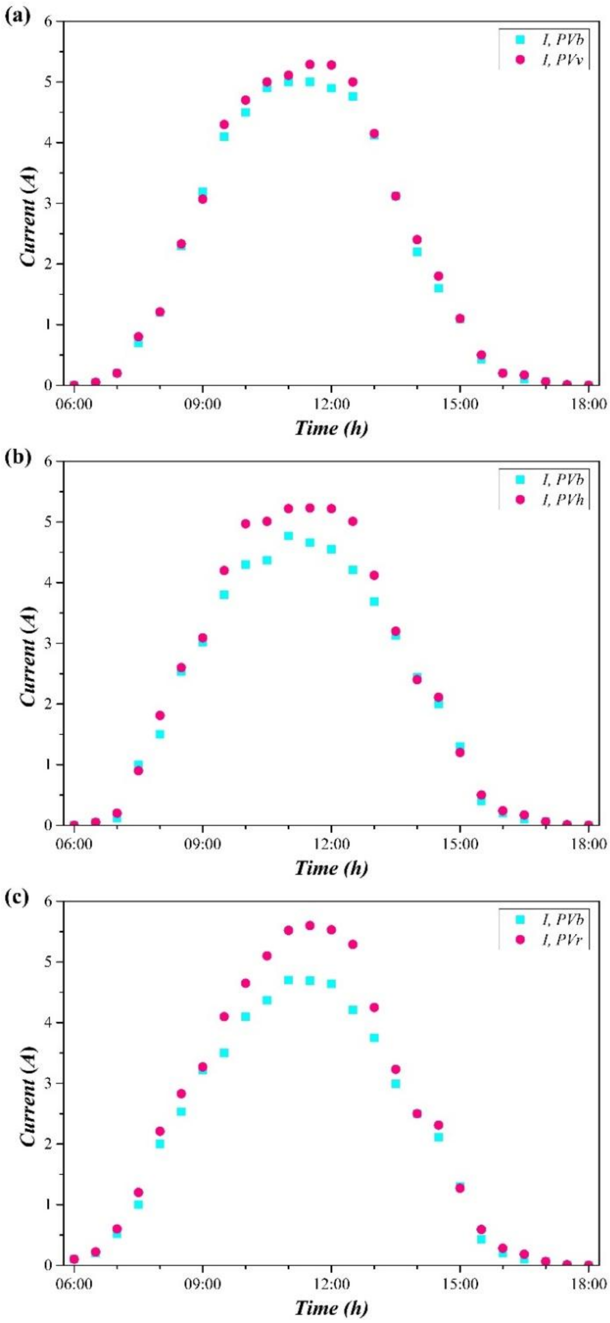

Figure 7. Current of PV panels (a) PV_b Vs. PVv, (b) PV_b Vs. PVh, (c) PV_b Vs. PVr

The voltage generated from PV panels followed the same trend as the current in all studied cases. The highest voltage for the PVv, PVh and PVr was 15.8, 16, and 16.5 V, respectively, whereas the PVb panel recorded 15.4, 15.8, and 16 V, respectively. The increase in current and voltage of modified PV panels over the base one is due to lower temperatures decreasing the internal resistance of the solar cells, allowing a more efficient electron flow. At rising temperatures, electron mobility in the semiconductor material diminishes, resulting in increased resistance and decreased current production. The fins enhance electron mobility by maintaining a cooler panel, augmenting the current output.

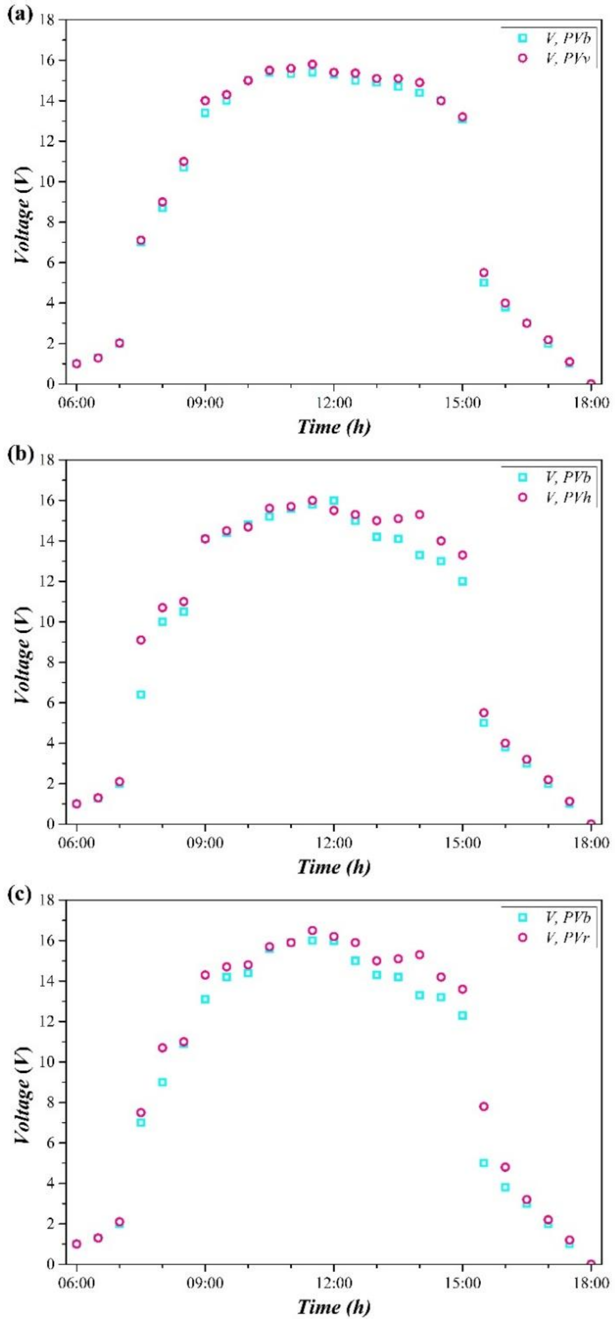

Figure 8. Voltage of PV panels (a) PVb vs. PVv, (b) PVb vs. PVh, (c) PVb vs. PVr

Figure 9 illustrates the impact of using fins with various orientations on the electrical power production of PV panels throughout the experimental days. As observed in the figure, the maximum difference in electrical power output between the finned PV and base PV panels was 6.54, 10, and 17 W in the case of vertical, horizontal, and random-arranged fins, respectively. Although PV panels equipped with fins consistently generated more power than the base PV, the findings revealed that the PV panel with randomly-arranged fins showed a better output power enhancement compared to the other two orientations during peak solar hours. This could be attributed to the wind direction variety in the location under study, improving the passive heat transfer mechanism and heat dissipation from the PV panel during the experimental period. Conclusively, it could be observed that fins help to lower the temperature of PV panels, enhancing the performance even at high weather temperatures.

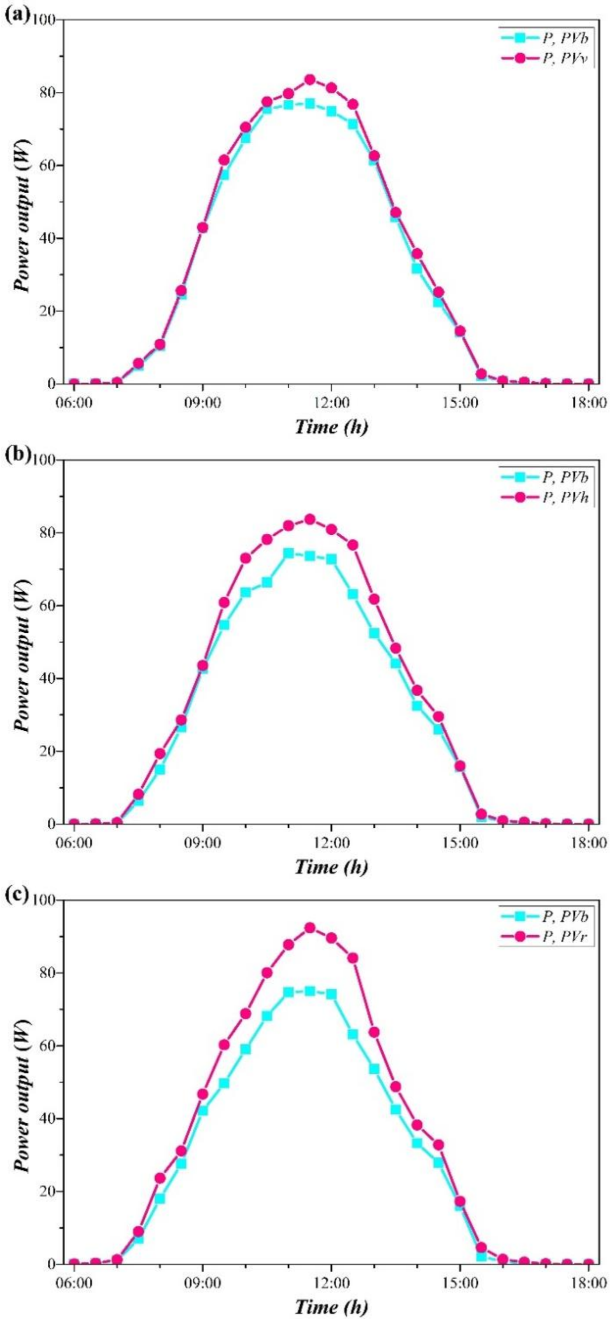

Figure 9. Power output of PV modules (a) PVb vs. PVv, (b) PVb vs. PVh, (c) PVb vs. PVr

Figure 10 demonstrates the electrical efficiency of PV panels under the three fin configurations. The electrical efficiency patterns across all configurations exhibited a standard daily trend, characterized by a gradual increase in efficiency from the morning, reaching a peak at midday, followed by a decline as sunlight decreases in the afternoon. The PV panel with fins (depicted in magenta) consistently demonstrated greater electrical efficiency than the base PV panels (shown in cyan) during peak solar hours. The maximum increment in the electrical efficiency in the finned PV panels compared with the base one recorded at 11:30 as 8.6 %, 13.7 % and 23.1 % in the case of vertical, horizontal and random fin arrangements, respectively. Although fins with a random pattern showed higher improvement, the output of all cases showed that fins have mitigated excessive temperature increment, which diminished the PV efficiency. However, the most notable efficiency improvement occurred at midday, when the thermal load on the panels is at its peak. This highlights the role of fins in regulating the temperatures and improving the performance of PV modules. The comparison of the three fin orientations indicates that each arrangement yields significant enhancements relative to the base case, although the extent of improvement may differ marginally based on the fin configuration. The findings indicated that employing fins in different orientations serves as an effective thermal management strategy to improve the efficiency of PV systems, with a superior performance for the random orientation.

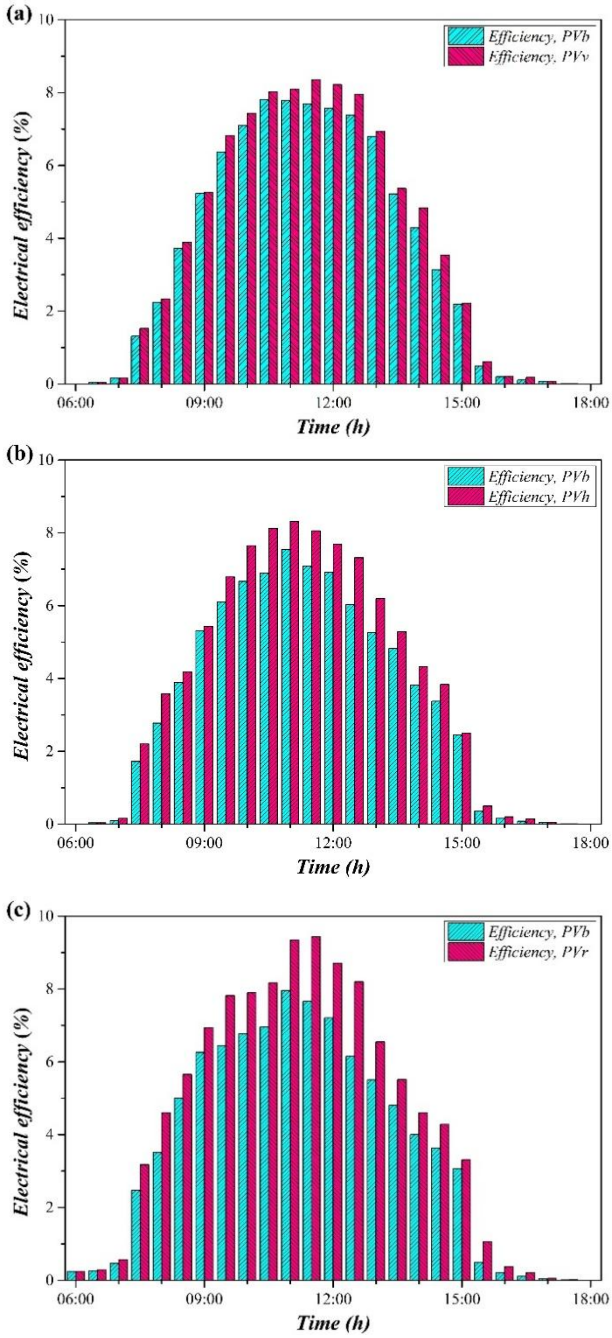

Figure 10. Efficiency of PV modules (a) PVb vs. PV_v, (b) PVb vs. PV_h, (c) PVb vs. PV_r

Table 4. Summary of literature studies on fins as a cooling technique

Reference	Study location	Fins mechanism	Power output enhancement	Electrical efficiency improvement
[42]	Beqaa, Lebanon	Aluminium finned plate	1.86 W	1.75 %
[43]	Beijing, China	U-shaped and L-shaped aluminium fins	1.8 %- 11.8 %	0.3 %- 1.8 %
[44]	National University of Malaysia	longitudinal and lapping fins and a planar reflector	----	10.68 %
[45]	Dezful, Iran	10 aluminium fins with a mirror	11.4 %	13.1 %
[46]	Shiraz, Iran.	Pin fins with a height of 6 cm	4 W	----
[47]	Baghdad, Iraq	Rectangular fins	15.3 %	----
[48]	Baghdad-Iraq	Open-cell copper metal foam fins	4.9 W	----
[49]	Baghdad, Iraq.	longitudinal aluminium fins	2.5 W	15.3 %
[50]	Baghdad, Iraq.	Staggered porous fins	----	4.7 %
[51]	New Zealand	PCM + External finned heat sink	----	12.9 %
Current study	Al Amarah City, Iraq	Aluminium L-shaped fins with different orientations (random orientation)	17 W	23.1 %

3.4 Comparative evaluation with literature studies

The outcomes achieved in the current paper are in good agreement with those reported in the literature under diverse weather conditions. Consequently, a summary of research findings is presented in Table 4, considering the investigated fins to improve the PV performance in terms of power output and electrical efficiency improvement. As can be noticed in the table, the results of the current study achieved unique values as compared with the literature findings. This could be attributed to the location's hot weather conditions, which showed the positive thermal effect of fins, even with simple design geometries. This could draw attention to the remarkable thermal performance that could be achieved with simple enhancers if designed properly for hot locations.

4. Conclusion

This experimental study investigates the effect of fin orientation on the PV panel performance improvement under hot weather conditions. A PV panel with vertically, horizontally, and randomly arranged 30 aluminium L-shaped fins was designed, tested, and compared considering the PV average surface temperature reduction, power output augmentation, and electrical efficiency improvement. The research findings revealed superior performance for the PV panel with fins, regardless of their orientation and wind speed, with the topmost cooling potential of the PV panel with the random orientation. As for cooling potential, the random arrangement of fins reached maximum average surface temperature reduction for the PV by 6.5 °C, influenced by wind vorticity within fins with various directions. The power output of the modified PV panel with the random arrangement was amended by up to 17 W over the reference PV, demonstrating a notable improvement in a single PV panel's output. Besides, the PV electrical efficiency was improved by about 23 % for randomly arranged fins, showing a noteworthy performance for passive fin application. Conclusively, random fin arrangement is a novel method to augment the heat sink performance for PV-modified fins passively, gaining vortices at low wind speeds. For future research, the impact of other environmental and external factors, such as wind turbulence, air humidity, and cloudiness, could be studied. Besides, the effect of dust accumulation and dust composition at different locations of Iraq could also be explored to overcome research questions in this research domain. The pattern of fin orientation adopted could also be explored, testing various configurations to specify the optimal random arrangement. In addition, economic concerns of using heat transfer modification techniques along with the PV panel cleaning would afford a wider overview of the proper techniques that could support the publicity of such technologies in low-income locations towards a cleaner future.

Ethical issue

The authors are aware of and comply with best practices in publication ethics, specifically with regard to authorship (avoidance of guest authorship), dual submission, manipulation of figures, competing interests, and compliance with policies on research ethics. The author adheres to publication requirements that the submitted work is original and has not been published elsewhere.

Data availability statement

The manuscript contains all the data. However, more data will be available upon request from the authors.

Conflict of interest

The authors declare no potential conflict of interest.

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