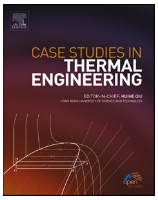
Case Studies in Thermal Engineering 50 (2023) 103400

Contents lists available at ScienceDirect

Case Studies in Thermal Engineering

journal homepage: www.elsevier.com/locate/csite



Performance enhancement of photovoltaic modules with passive cooling multidirectional tapered fin heat sinks (MTFHS)

Siti Nuraisyah Razali [a], Adnan Ibrahim [a,*], Ahmad Fazlizan [a,**], Mohd Faizal Fauzan [a], Raheem K. Ajeel [a], Emy Zairah Ahmad [b], Win Eng Ewe [c], Hussein A. Kazem [d]

[a] *Solar Energy Research Institute, Universiti Kebangsaan Malaysia, 43600, Bangi, Selangor, Malaysia*
[b] *Fakulti Teknologi Kejuruteraan Elektrik dan Elektronik, Universiti Teknikal Malaysia Melaka, Hang Tuah Jaya, 76100, Durian Tunggal, Melaka, Malaysia*
[c] *Energy Systems Research Unit, Mechanical and Aerospace Engineering, University of Strathclyde, Glasgow, G1 1XJ, Scotland, United Kingdom*
[d] *Faculty of Engineering, Sohar University, PO Box 44, Sohar, PCI 311, Oman*

ARTICLE INFO

Keywords:
Passive cooling
Performance enhancement
Multidirectional tapered fins
Temperature reduction

ABSTRACT

The electrical output of photovoltaic (PV) modules degrades with continued exposure to extreme temperatures caused by solar radiation. The uniqueness of this research lies in the utilization of multidirectional fins with varying heights, which effectively accelerate heat transfer in PV cooling systems by inducing a transition in the boundary layer within the confined zone of the fins. The research aims to investigate the effect of using Multidirectional Tapered Fin Heat Sinks (MTFHS) to improve the efficiency of PV modules by utilizing aluminum alloy material as heatsinks. The proposed multidirectional design aims to facilitate enhanced heat transfer by promoting airflow in the central area of the PV module. The experimental procedures in our study differ from previous research as we utilized the latest generation of PV modules (405 Wp, PERC Half-cut cells) to fill the discrepancy between laboratory-based investigations and practical applications. Two PV modules were tested for an outdoor parametric analysis under outdoor operating conditions, with solar irradiance recorded from 200 to 1000 W/m^2 and ambient temperatures ranging from 26° to 38 °C. Findings indicated that the proposed MTFHS could lower PV module temperatures by 12 °C. Reduced temperature boosts PV module efficiency by 1.53%. Cooling advancements proved vital in contributing to sustainability in PV system installations.

1. Introduction

Renewable energy's revolutionary potential extends beyond its environmental benefits, driven by its sustainability and abundance. By embracing and optimizing renewable energy sources such as solar, wind, hydro, and geothermal, a transformative cycle of global economic expansion and ecological care can be initiated [1]. Recently, solar energy has become one of the leading renewable energy sources with tremendous development potential to generate electricity is essential not only for meeting our energy needs but also for addressing pressing global environmental challenges [2]. However, the photovoltaic (PV) module is vulnerable to a rise in surface temperatures that adversely affects the overall PV system performance [3,4]. It is estimated that for every 1 °C increase in ambient

---

[*] Corresponding author.
[**] Corresponding author.
E-mail address: iadnan@ukm.edu.my (A. Ibrahim).

https://doi.org/10.1016/j.csite.2023.103400
Received 26 February 2023; Received in revised form 4 August 2023; Accepted 18 August 2023

temperature, there is a 0.4–0.5% point loss in efficiency [5].

As a result, many approaches to cooling PV modules have recently been investigated as promising approaches to rectify these issues [6]. Indeed, one effective approach to passive cooling for PV modules is using a heatsink at the rear back of the module. A heatsink is a thermal conductor that absorbs and dissipates heat away from the PV module. When placed at the back of the module, it serves as a cooling mechanism by enhancing heat transfer and improving the overall thermal performance of the system. The performance of solar modules is influenced by various parameters, including heat transfer area and wind [7]. Ahmad et al. [8] comprehensively reviewed various fin design configurations: cross-fin, perforated-fin base, lateral perforated fin, displaced fin, triangular fin, and wavy fin. Table 1 shows various experimental passive cooling studies, including the present research, highlighting the fin design and the impact on temperature reduction and PV performance improvement.

The proposed multidirectional tapered fins represent a novel approach that significantly aids in promoting airflow for enhanced heat transfer in PV modules. Unlike previous studies focusing mostly on rectangular fin design geometry, our research explores the unique benefits of utilizing these innovative multidirectional tapered fins. The overall framework of the journal encompasses three key stages: Firstly, developing an optimized fin design, incorporating the multidirectional tapered fins to maximize heat dissipation efficiency. Secondly, the experimental stage, where the designed cooling system is tested under real-world conditions to gather data on its performance. Finally, the analysis stage involves comprehensive evaluation and interpretation of the experimental results, enabling a deeper understanding of the cooling system’s effectiveness and potential for practical applications.

2. Methodology

2.1. PV module efficiency and measurement uncertainties

The electrical efficiency of the PV modules depends on the mean temperature of the module can be expressed as follows:

$$\eta_{\mathrm{eff}} = \eta_{\mathrm{eff}}\left[1 - \beta_{\mathrm{eff}}\left(T_{\mathrm{cell}} - T_{\mathrm{reff}}\right)\right] \tag{1}$$

η_{eff} is the PV module efficiency at STC (1000 W/m^2, 25°C), T_{cell} is the experimentally determined mean PV module cell temperature, β_{eff} is the relative temperature coefficient of the cell and T_{reff} is the reference temperature measured at 25 °C.

Uncertainty analysis measures approximation errors, measurement errors, and accuracy. The standard deviation can be calculated as follows:

$$s = \sqrt{\frac{\Sigma_{\mathrm{i}}^{n}\left(x_{\mathrm{i}} - \bar{x}\right)^{2}}{n - 1}} \tag{2}$$

x_{i}, $\bar{x}$, and n indicates measurement means, findings, and measurement sets. The uncertainty (u) expression is shown as follows:

$$u = \frac{s}{\sqrt{n}} \tag{3}$$

2.2. Repetition uncertainties

The investigation encompassed the evaluation of data uncertainty within the experiment to ascertain the validity and credibility of the findings, which could be susceptible to potential errors. The uncertainties arising from the assessment procedure in the independent variables are denoted as W_1, W_2, …., W_n, while the uncertainties in the results, W_R, are determined from the provided expression, where X_1, X_2, …, Xn represent the independent variables [21,22].

$$W_R = \left[\left(\frac{\partial R}{\partial X_1}W_1\right)^2 + \frac{\partial R}{\partial X_2}W_2\right)^2 + \ldots\ldots + \frac{\partial R}{\partial X_n}W_n\right)^2\Bigg)\Bigg]^{\frac{1}{2}} \tag{4}$$

Table 1
Recent advancements in passive cooling with fins.

Ref.	Year	Location	Fins design	PV Technology/Capacity (wp)	Temperature reduction (°C)	Performance improvement (%)
[9]	2020	Turkey	Rectangular	Si poly (75)	2.4 °C	2.14%
[10]	2020	Jordan	Rectangular	Si poly (250)	–	5.80%
[11]	2021	Iraq	Longitudinal	Si poly (50)	5.5 °C	1.30%
[12]	2021	Romania	Perforated	Si mono (320)	–	4.99%
[13]	2021	Mexico	Discontinuous	Si poly (50)	5.0 °C	2.96%
[14]	2021	Malaysia	Lapping	Si poly (40)	–	10.68%
[15]	2022	Malaysia	Multilevel height	Si mono (120)	8.45 °C	9.56%
[16]	2022	China	Rectangular	Bifacial (n/a)	11.9 °C	4.4%
[17]	2022	UAE	Rectangular	Si mono (290)	6.3 °C	3.0%
[18]	2022	India	Rectangular	Thin film (n/a)	10.0 °C	5.47%
[19]	2022	Egypt	Rectangular	Si poly (83)	–	22.4%
[20]	2023	Hungary	Rectangular	Si poly (50)	–	5.48%
Present work	2023	Malaysia	Multidirectional Tapered	Si mono (405)	12 °C	1.53%

According to eq. (4), the upper bound of uncertainty in electrical efficiency was estimated as:

$$\left(\left(\frac{\partial\eta_{elec}}{\partial I_m}W_{I_m}\right)^2+\frac{\partial\eta_{elec}}{\partial V_m}W_{V_m}\right)^2+\ldots\ldots+\frac{\partial\eta_{elec}}{\partial G_m}W_G\right)^2\right)^{\frac{1}{2}}=\pm 0.2 \qquad (5)$$

An acceptable level of maximum uncertainty, below 5%, was accepted as suitable for assessments of electrical efficiency.

3. Experimental setup

Half-cut cell mono PERC PV panels with a module efficiency of 20.13% were used in this experiment. The novel design of the Multidirectional Tapered Fin Heat Sink (MTFHS) is attached at the back of the panel, as shown in Fig. 1. Aluminium alloy is used for PV module cooling fins. Each PV module had its back temperature tested at six different spots. One PV module was bare, while another had MTFHS fins added to the backplate to test outdoor electrical performance. Fig. 1 shows the experimental setup overview, and Table 2 lists the experimental specifications for outdoor setup (see Fig. 2).

The uncertainty analysis of standard tools is determined in Table 3. The data is collected and evaluated in accordance with solar irradiance, ambient temperature, temperature decrease, and panel performance. Using Equation (1), the electrical efficiency is determined. It is shown that the uncertainty of the measuring devices was less than 2%.

4. Results and discussions

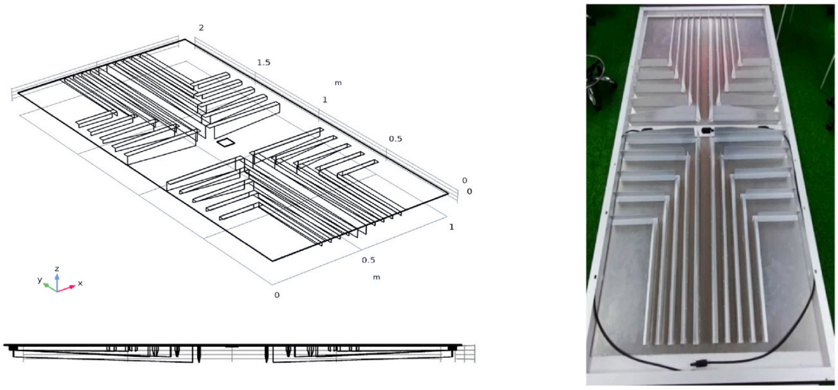
4.1. PV module temperature

The temperature reduction of PV modules with and without heat sink fins was observed and compared using the mean plate temperature (T_{cell}). This approach proved ideal for obtaining precise and accurate results [23]. Based on recorded measurements, the fins heatsink significantly impacts the PV module temperature uniformity. Fig. 3 shows irradiance and ambient temperature data from 11:00 a.m. to 4:00 p.m. It indicates a 200–1000 W/m^2 average irradiance and a 26–38 °C ambient temperature. The highest temperature outside is approximately 38 °C at 1:25 p.m.

PV modules with MTFHS fins and those without are differentiated by cooling performance. Fig. 4 shows the difference in cooling efficiency between reference modules and those integrated with MTFHS fins is evident, with a notable maximum temperature reduction of 12 °C observed at an irradiance of 1000 W/m^2. This significant improvement in temperature regulation highlights the positive impact of MTFHS on the overall performance of PV systems. Furthermore, the time of the day also influences the cooling effect of heat sinks. During solar noon, the MTFHS fins demonstrate an 8.33% greater impact on temperature reduction than the morning and night periods. This variation indicates that the cooling effectiveness is dynamic and varies with the intensity of solar radiation throughout the day.

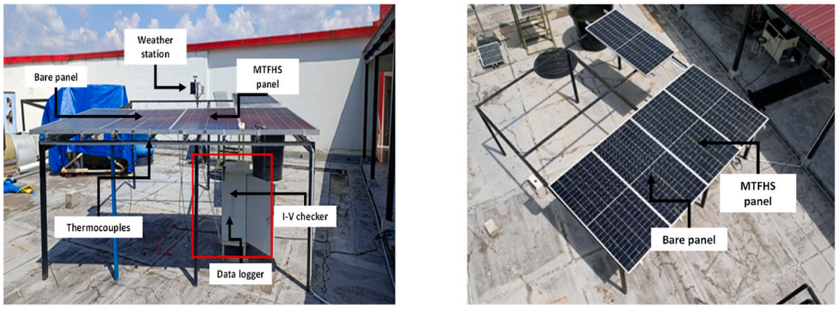
A specific case study involving a PV module with MTFHS reveals compelling data. The module's maximum temperature reaches a favorable 57 °C under the influence of these heat sinks, while its end-of-day temperature remains at a relatively low 46 °C. In contrast, a PV module without fins experiences higher temperatures, peaking at 51 °C and possibly reaching as high as 69 °C by the end of the day. This sharp constant underscores the substantial benefits of integrating MTFHS fins to manage temperature in hot climates effectively.

The results of these studies highlight not only the cooling advantages but also the reliability of solar modules under diverse operational conditions. The fact that the module's temperature consistently surpasses the ambient temperature reinforces the significance of proper temperature regulation. MTFHS fins facilitate the heat exchange process, increasing the surface area available for dissipation and automatically lowering the PV panel's temperature.



(a) (b)

Fig. 1. The experimental setup overview.



(a) (b)

Fig. 2. (a) The experimental test rig consists of a weather station, I–V checker, and data logger (b) The top view of both bare and proposed MTFHS panels are mounted on the same plane.

Table 2
Technical specifications of PV module.

Criteria	Description
Coordinate of location	2°55’38.4"N 101°46’05.3"E (Bangi, Malaysia)
PV technical specifications at STC	405 Wp - PERC half-cut cells technology Open circuit, V_{OC}: 50.1 V Short circuit current, I_{SC}: 10.48 A Electrical efficiency, η_{eff} : 20.13% Relative temperature coefficient, B_{eff}: 0.004

Table 3
Uncertainty analysis of each standard tool.

Measurement instruments	Parameters (units)	Model names	Uncertainties
Thermocouples	Temperature (°C)	K-type	±0.1 °C
Current-voltage checker	Voltage (V), Current (A), Power (W)	MP-11	±0.65%
Weather station	Irradiance (W/m^2)	RK600-07	±1.3%
	Wind speed (m/s)		±1.45%

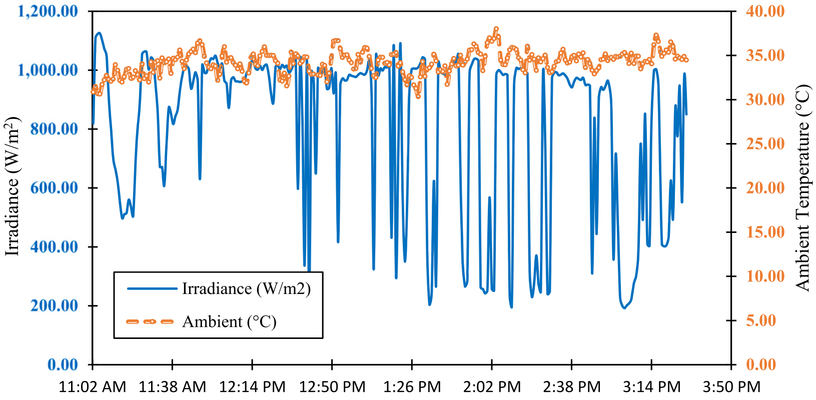


Fig. 3. Irradiance and ambient temperature recorded on-site.

4.2. *Electrical performance characteristics*

Temperature fluctuations within the photovoltaic (PV) module can exert detrimental effects on the efficiency of its electrical output. Consequently, to comprehensively assess and characterize the performance of the PV module, a current-voltage (IV) curve assumes critical importance. In pursuit of this, key electrical parameters, including the short-circuit current (Isc), open-circuit voltage (Voc), and maximum power (Pmax), were meticulously measured and subjected to thorough analysis. The experimental design rigorously subjected these assessments to actual operating conditions, ensuring the robustness and relevance of the findings. As

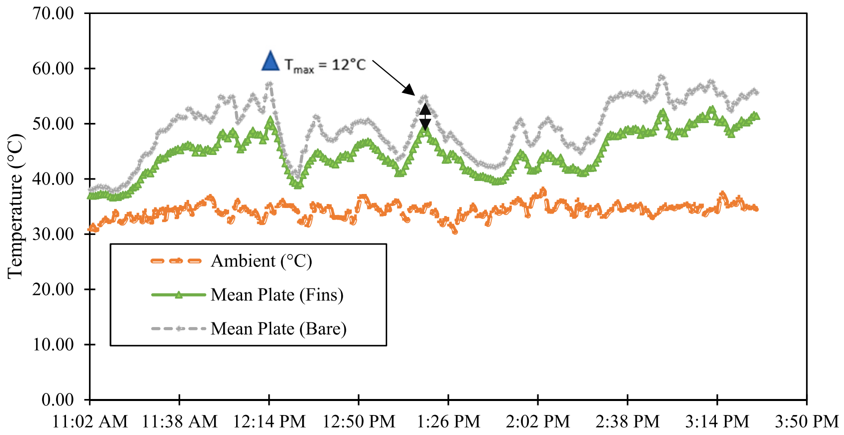
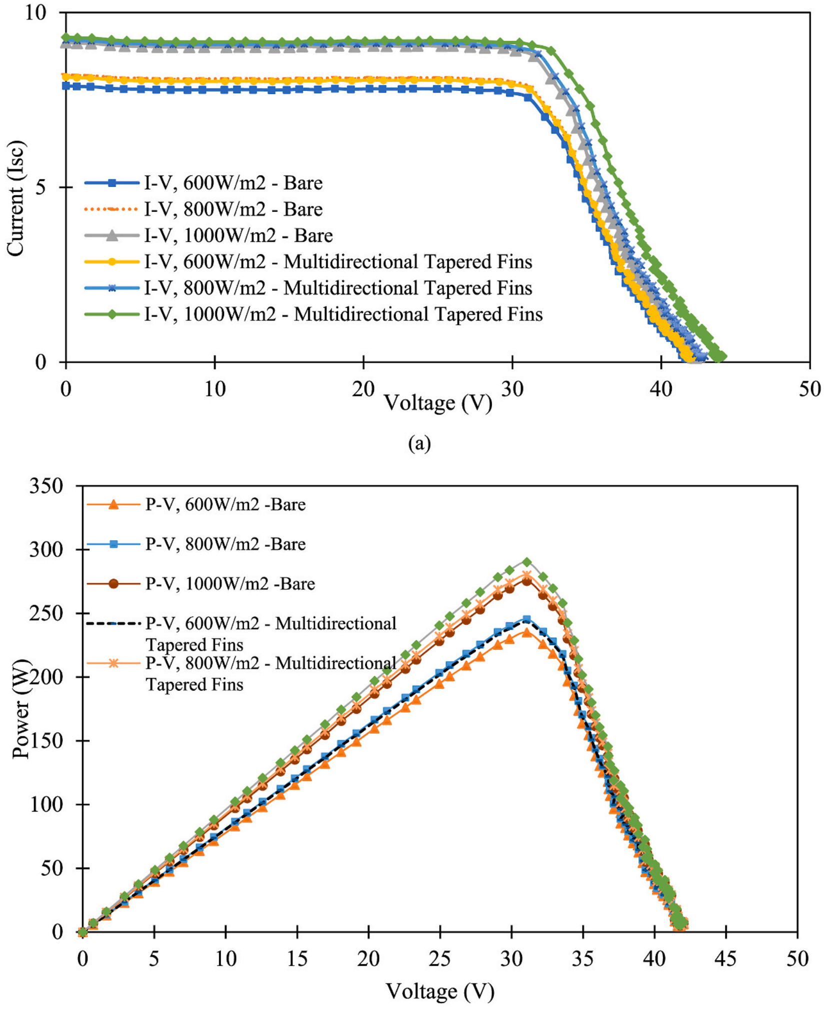


Fig. 4. Temperature variations of the panel with fins, bare panel, and ambient temperature.



(a)

(b)

Fig. 5. (a) I–V curve, (b) P–V curve.

depicted in Fig. 5 (a) and (b), a discernible contrast exists between the current-voltage (I–V) and power-voltage (P–V) curves of the unenhanced bare solar module and the solar module augmented with multidirectional tapered fin heat sinks (MTFHS) within the irradiance range of 200–1000 W/m^2. This disparity arises primarily due to the semiconductor nature of the solar cells, wherein temperature elevation amplifies the generation of charge carriers, thereby expanding the depletion zone, commonly known as the charge separation layer.

A detailed examination of the PV modules illustrated in Fig. 5 (a) reveals that the inclusion of the MTFHS heatsink resulted in a marginal enhancement of the output current while inducing a significant rise in voltage, effectively optimizing the electrical characteristics. The augmentation in voltage is attributed to the improved heat dissipation capacity of the module, facilitated by the MTFHS, operating through natural convection. Consequently, this enhanced heat dissipation fosters an average output current escalation from 9.21A to 9.27A, demonstrating the tangible benefits of integrating MTFHS in electrical performance optimization. The research findings reveal a noticeable presence of a heat sink phenomenon during the initial stages of operation. As external temperatures increase, causing a slowdown in the heat transfer process, and the intensity of the sun's rays diminishes, the influence of the heat sink gradually diminishes as well, resulting in a gradual reduction in electricity generation. This observation underscores the importance of understanding the transient nature of the heat sink effect and its implications on the overall performance and efficiency of the system.

Based on the data presented in Fig. 5 (b), it is evident that integrating a multidirectional tapered fin heat sink (MTFHS) enables the solar module to deliver significantly higher electrical output, reaching up to 290W. In contrast, without MTFHS, the electricity generation capacity is notably lower, reaching only 243W. In real-world outdoor operational scenarios, particularly in regions with high solar irradiance, maintaining the module temperature at an ideal 25 °C becomes unfeasible. As a result, the actual electrical output falls below the maximum output achievable under standard test conditions (STC), specified as 405W. As indicated in the PV datasheet, a specific and explicit mention is made regarding the power coefficient of the PV panel, which is expected to decrease to −0.35% per degree Celsius when operating under real-world conditions. This observation underscores the practical significance of heat sink implementation and its influence on the overall electrical performance of the solar module.

As illustrated in Fig. 6, the electrical efficiency of a photovoltaic (PV) module coupled with MTFHS surpasses that of a bare PV module at varying irradiance levels of 600, 800, and 1000 W/m^2. Remarkably, the most substantial disparity in photovoltaic efficiency is observed at 1000 W/m^2, amounting to an impressive 1.53% difference. The attained relative efficiency of 18.98% reflects a notable and encouraging improvement of 1.53%. This achievement demonstrates a commendable advancement in the system's overall efficiency, signifying a significant enhancement in its ability to convert solar energy into useable electricity. The observed gain in efficiency holds promising implications for optimizing energy generation and further enhancing the performance of the photovoltaic system. Such progress is essential to realizing greater sustainability and efficacy in solar energy applications.

In conclusion, the integration of MTFHS in PV modules demonstrates a clear advantage in terms of cooling performance. The substantial temperature reduction observed under various irradiance levels and times of day confirms the effectiveness of these heat sinks in hot climates. Moreover, the improved heat exchange surface area provided by the back fins of the solar module contributes to its reliability and longevity, making it a valuable solution for optimizing the performance and efficiency of photovoltaic systems and other solar applications.

5. Conclusions

A comprehensive field experiment examined the effects of multidirectional tapered fin heat sinks (MTFHS) on solar modules' thermal characteristics and operational efficiency. The study assessed the efficacy of MTFHS in photovoltaic (PV) modules under controlled and identical tropical temperature settings by comparing their performance with typical bare PV modules. The following key findings were established:

1. A remarkable reduction in PV module temperature was observed when leveraging MTFHS technology. The application of MTFHS led to a notable decrease in temperature from 69 °C to a more favorable 57 °C, representing a substantial 12 °C temperature difference under an irradiance of 1000 W/m^2. This reduction underscores the impressive cooling capabilities of the MTFHS, mitigating potential overheating issues.
2. Integrating MTFHS also improved PV module electrical efficiency across different irradiance levels. At solar irradiance values of 600, 800, and 1000 W/m^2, the MTFHS positively impacted photovoltaic efficiency. Particularly at 1000 W/m^2, the photovoltaic efficiency differential reached an impressive 1.53%, highlighting the potential for enhanced energy generation with this technology.
3. The multidirectional shape of the fins design was revealed to be a key factor influencing both module performance and solar module temperature. The intricate configuration of the fins influenced heat dissipation and airflow patterns, affecting the PV module's thermal characteristics and overall efficiency.
4. To further optimize PV module performance, future studies are recommended to focus on reducing high temperatures within the central region of PV modules and preventing the formation of hotspots during heat dissipation. An avenue for exploration lies in combining the findings of this study with forced convection techniques, which have the potential to enhance cooling effectiveness and further increase the overall energy conversion efficiency.

In conclusion, this comprehensive investigation into the effects of multidirectional tapered fin heat sinks (MTFHS) on solar module performance has provided valuable insights. The integration of MTFHS proves to be a promising solution for managing PV module temperatures, enhancing electrical efficiency, and optimizing the performance of solar modules in tropical climates. The study's

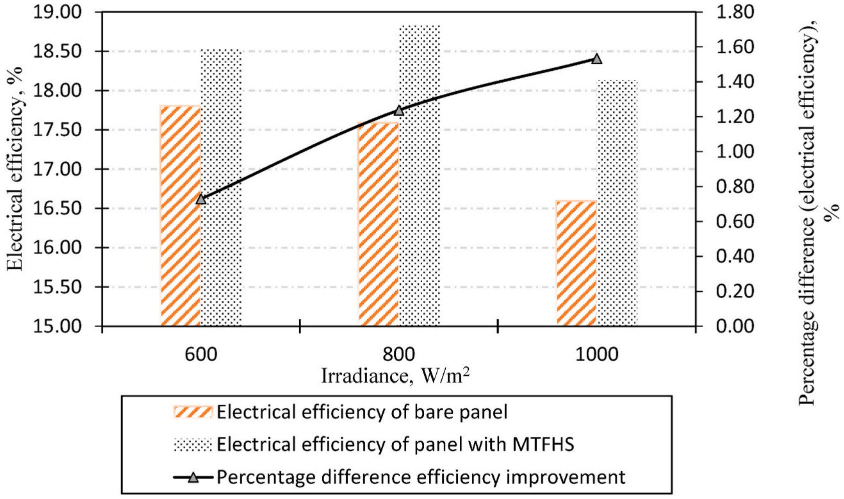


Fig. 6. Electrical efficiency of bare PV and PV modules with MTFHS fins.

findings offer a stepping stone toward advancing the efficiency and reliability of solar systems and other applications.

Author statement

Siti Nuraisyah Razali has devised the conceptual ideas, including writing, reviewing, designing the model, computational framework data analysis, and draft preparation. Ahmad Fazlizan, Mohd Faizal Fauzan and Emy Zairah Ahmad have verified the analytical methods and investigation. Win Eng Ewe and Hussein A. Kazem and Raheem K. Ajeel have further corrected the computational framework and data analysis. Adnan Ibrahim performed the visualization and funding acquisition and supervised the findings of this work.

All authors discussed the results and contributed to the final and revised manuscript.

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.

Data availability

Data will be made available on request.

Acknowledgment

The Fundamental Research Grant Scheme (FRGS/1/2019/TK07/UKM/02/4) supported the research project, which the authors would like to acknowledge.

References

[1] M.A.A. Rahmat, et al., An analysis of renewable energy technology integration investments in Malaysia using HOMER pro, Sustainability 14 (20) (2022), https://doi.org/10.3390/su142013684.

[2] I. Hasan, Enhancement the performance of PV panel by using fins as heat sink, Engineering and Technology Journal 36 (7A) (2018) 798–805, https://doi.org/10.30684/etj.36.7A.13.

[3] H.A. Kazem, M.T. Chaichan, A.H.A. Al-Waeli, H. Jarimi, A. Ibrahim, K. Sopian, Effect of temperature on the electrical and thermal behaviour of a photovoltaic/thermal system cooled using SiC nanofluid: an experimental and comparison study, Sustainability 14 (19) (2022), https://doi.org/10.3390/su141911897.

[4] R. Parthiban, P. Ponnambalam, An enhancement of the solar panel efficiency: a comprehensive review, Front. Energy Res. 10 (Jul. 14, 2022), https://doi.org/10.3389/fenrg.2022.937155. Frontiers Media SA.

[5] R. Parthiban, P. Ponnambalam, An enhancement of the solar panel efficiency: a comprehensive review, Front. Energy Res. 10 (July) (2022) 1–15, https://doi.org/10.3389/fenrg.2022.937155.

[6] A. Sufiyan Abd Hamid, et al., Techno-economic Analysis of a Hybrid Solar Dryer with a Vacuum Tube Collector for Hibiscus Cannabinus L Fiber, 2020 [Online]. Available: https://www.researchgate.net/publication/347647040.

[7] A.F. Ismail, A.S.A. Hamid, A. Ibrahim, H. Jarimi, K. Sopian, Performance analysis of a double pass solar air thermal collector with porous media using lava rock, Energies 15 (3) (2022), https://doi.org/10.3390/en15030905.

[8] E.Z. Ahmad, A. Fazlizan, H. Jarimi, K. Sopian, A. Ibrahim, Enhanced heat dissipation of truncated multi-level fin heat sink (MLFHS) in case of natural convection for photovoltaic cooling, Case Stud. Therm. Eng. 28 (March) (2021), 101578, https://doi.org/10.1016/j.csite.2021.101578.

[9] F. Bayrak, H.F. Oztop, F. Selimefendigil, Experimental study for the application of different cooling techniques in photovoltaic (PV) panels, Energy Convers. Manag. 212 (April) (2020), 112789, https://doi.org/10.1016/j.enconman.2020.112789.

[10] M.R. Gomaa, W. Hammad, M. Al-Dhaifallah, H. Rezk, Performance enhancement of grid-tied PV system through proposed design cooling techniques: an experimental study and comparative analysis, Sol. Energy 211 (Nov. 2020) 1110–1127, https://doi.org/10.1016/j.solener.2020.10.062.

[11] A.A. Farhan, D.J. Hasan, An experimental investigation to augment the efficiency of photovoltaic panels by using longitudinal fins, Heat Transfer 50 (2) (Mar. 2021) 1748–1757, https://doi.org/10.1002/htj.21951.

[12] S.V. Hudișteanu, F.E. Țurcanu, N.C. Cherecheș, C.G. Popovici, M. Verdeș, I. Huditeanu, Enhancement of pv panel power production by passive cooling using heat sinks with perforated fins, Appl. Sci. 11 (23) (Dec. 2021), https://doi.org/10.3390/app112311323.

[13] J.G. Hernandez-Perez, J.G. Carrillo, A. Bassam, M. Flota-Banuelos, L.D. Patino-Lopez, Thermal performance of a discontinuous finned heatsink profile for PV passive cooling, Appl. Therm. Eng. 184 (Feb. 2021), https://doi.org/10.1016/j.applthermaleng.2020.116238.

[14] A.M. Elbreki, A.F. Muftah, K. Sopian, H. Jarimi, A. Fazlizan, A. Ibrahim, Experimental and economic analysis of passive cooling PV module using fins and planar reflector, Case Stud. Therm. Eng. 23 (Feb) (2021), https://doi.org/10.1016/j.csite.2020.100801.

[15] E.Z. Ahmad, K. Sopian, A. Fazlizan, H. Jarimi, A. Ibrahim, Outdoor performance evaluation of a novel photovoltaic heat sinks to enhance power conversion efficiency and temperature uniformity, Case Stud. Therm. Eng. 31 (Mar. 2022), https://doi.org/10.1016/j.csite.2022.101811.

[16] J. Li, et al., Performance evaluation of bifacial PV modules using high thermal conductivity fins, Sol. Energy 245 (Oct. 2022) 108–119, https://doi.org/10.1016/j.solener.2022.09.017.

[17] F. Al-Amri, F. Saeed, M.A. Mujeebu, Novel dual-function racking structure for passive cooling of solar PV panels –thermal performance analysis, Renew. Energy 198 (Oct. 2022) 100–113, https://doi.org/10.1016/j.renene.2022.08.047.

[18] G. Raina, S. Sinha, G. Saini, S. Sharma, P. Malik, S. Thakur, Assessment of photovoltaic power generation using fin augmented passive cooling technique for different climates, Sustain. Energy Technol. Assessments 52 (PB) (2022), 102095, https://doi.org/10.1016/j.seta.2022.102095.

[19] N.A.S. Elminshawy, D.G. El-Damhogi, I.A. Ibrahim, A. Elminshawy, A. Osama, Assessment of floating photovoltaic productivity with fins-assisted passive cooling, Appl. Energy 325 (Nov) (2022), https://doi.org/10.1016/j.apenergy.2022.119810.

[20] M. Alktranee, P. Bencs, Experimental comparative study on using different cooling techniques with photovoltaic modules, J. Therm. Anal. Calorim. 148 (9) (May 2023) 3805–3817, https://doi.org/10.1007/s10973-022-11940-1.

[21] N.A.S. Elminshawy, A.M.I. Mohamed, A. Osama, I. Amin, A.M. Bassam, E. Oterkus, Performance and potential of a novel floating photovoltaic system in Egyptian winter climate on calm water surface, Int. J. Hydrogen Energy 47 (25) (2022) 12798–12814, https://doi.org/10.1016/j.ijhydene.2022.02.034.

[22] N. Elminshawy, A. Elminshawy, A. Osama, M. Bassyouni, M. Arıcı, Experimental performance analysis of enhanced concentrated photovoltaic utilizing various mass flow rates of Al2O3-nanofluid: energy, exergy, and exergoeconomic study, Sustain. Energy Technol. Assessments 53 (2022), 102723, https://doi.org/10.1016/j.seta.2022.102723.

[23] M. Rajvikram, G. Sivasankar, Experimental study conducted for the identification of best heat absorption and dissipation methodology in solar photovoltaic panel, Sol. Energy 193 (September) (2019) 283–292, https://doi.org/10.1016/j.solener.2019.09.053.