



Research Article

Experimental evaluation of hybrid electric-heat operation for reliable residential water heating technology using photo-thermal system

Ahmad Ilzam Anshori HASIBUAN¹, Ridwan NURDIN², Ismail ISMAIL^{1,3},
Reza Abdu RAHMAN^{1,3*}

¹Department of Mechanical Engineering, Faculty of Engineering, Universitas Pancasila, DKI Jakarta 12640, Indonesia

²Department of Energy Conversion Engineering, Politeknik Negeri Bandung, Bandung Barat 40559, Indonesia

³Center for energy storage system, Universitas Pancasila, DKI Jakarta 12640, Indonesia

ARTICLE INFO

Article history

Received: 22 November 2024

Revised: 18 February 2025

Accepted: 25 February 2025

Keywords:

Amperage; Coolant; Flowrate;
PVT; Sand; Thermal

ABSTRACT

Photovoltaic (PV) is equipped with additional cooling system to reduce the cell temperature and enhance its efficiency. Numerous studies have addressed the issue using various methods such as thermoelectric, passive, and active cooling. In this work, the excess heat is taken as additional energy input considering the trend of PV direct heating system. The present study introduces PV and thermal collector as one compact system for heating application. PV output is connected to heating element while thermal collector harvests the waste heat from PV module. It allows the system to accumulate higher effective heat energy, which is useful for residential water heating applications. Experimental work is performed using 50 Wp monocrystalline PV by varying the filler material (sand and grease) inside the thermal collector and flowrate of the working fluid. The effect of filler material is observed as rapid heat dissipation, which is obtained by sand. Also, coolant flowrate affects the maximum temperature output and the accumulated heat energy from PV module. Despite the variation, the cooling effect from thermal collector reduces the PV temperature up to 30.1% and enhances the electric generation by 15.1%. The collected heat energy reaches a maximum value of 129.3 Watts, while peak electricity output only 46.4 Watts. The heated water from PV output reaches maximum temperature of 75 °C with maximum coolant temperature of 48.7 °C. It shows that the system is highly reliable for residential heating, offering a compact PV-thermal collector with higher power output.

Cite this article as: Hasibuan AIA, Nurdin R, Ismail I, Rahman RA. Experimental evaluation of hybrid electric-heat operation for reliable residential water heating technology using photo-thermal system. J Ther Eng 2025;11(6):1717–1728.

INTRODUCTION

Despite population growth on global scale, utilization of fossil fuel transforms into cleaner energy. It shows serious

acts to mitigate severe climate change. The engineering process for utilizing biomass and renewable sources [1–3] indicates positive achievement on higher portion of renewable

*Corresponding author.

*E-mail address: reza.a@univpancasila.ac.id

This paper was recommended for publication in revised form by
Editor-in-Chief Ahmet Selim Dalkilic



sources in energy mix. However, global projection reveals that annual energy consumption tends to increase [4], so further effort is required to maximize the potential of clean energy sources, particularly for building sector. The sector is ideal for being role model in the application and utilization of clean energy technology to meet the local demand, such water heating. Moreover, residential heating consumes enormous amounts of energy [5]. It makes additional improvements in supplying clean energy for the sector is essential.

Solar energy is essential for supplying hot water in residential housing through solar thermal technology [6]. It uses specific thermal collector to enhance the energy intake from the sun [7]. The system reliability is enhanced by coupling the collector with thermal storage, which utilizes latent and sensible heat of the material [8–10], making the system operate at longer duration with higher capacity. Moreover, recent trend indicates alternative option to operate photovoltaic (PV) as input energy for heating purposes. The work [11] assessed the potential of PV for the heating sector, implying that around 48% of the required energy for heating purposes can be supplied by PV. The concept offers one significant advantage regarding novel configuration to store the excess energy production from PV. Different assessment was taken [12] for the idea, emphasizing the positive contribution of PV for supplying heating demand in residential sector under suitable control process. Thus, it adds a new option for applying PV system specifically designed for hot water generation.

PV operates using photoelectric, which converts sunlight into electrical energy. The process increases the surface temperature (SUT) of the PV. It is considered waste heat for the system operation [13]. It disrupts the conversion process, significantly decreasing the PV efficiency. The system requires additional cooling system to maintain the optimum working temperature of PV. The basic method is passive cooling, which operates without working fluid [14]. It is located at backsheet (BS) assembly of PV module. M. B. Elsheniti et al. developed heat management under passive mode operation for PV modules, resulting in a higher power output around 5.75% compared to the reference module [15]. Increasing the cooling capacity was conducted using dual model cooling system, achieving a better thermal and electrical efficiency at 24.3% and 0.16% [16]. It shows that heat management is essential to prevent inefficient output from PV modules.

Another method is developed specifically concerned with the operating condition of PV cooling system. H. Chen et al. evaluated intermittent cooling for PV modules with nanofluids, indicating that electric generation efficiency increases 19.7% [17]. Q. Wang et al. employed heat pipes and iron-oxide nanofluids for PV cooling system, showing the SUT reduces around 20.4 °C [18]. Adjustment of the type of nanofluid and operating system contributes notably to enhancing the capability of the system, as summarized in this work [19]. The heat exchange is the key

aspect to ensuring the effective cooling process. Installing additional fin at BS enhances the heat exchange, particularly under suitable fin orientation [20]. Also, different cooling mechanism is proposed by employing magnetic field. Numerical optimization was performed here [21] by introducing an additional magnetic field for the system, revealing a better heat distribution corresponding to higher cell efficiency. It demonstrates the urgency of performing a cooling mechanism to maintain the effective output of PV modules. Despite that, the usability of nanofluids and extensive equipment may result in high installment cost, reducing the net energy balance and potentially bringing negative drawbacks at night [22].

The accumulated waste heat from PV operation is another form of solar energy potentially harvested as additional energy input. Thus, several works focus on utilizing the energy through thermoelectric (TE). This study [23] conducted numerical analysis for PV cooling system with TE, demonstrating the potential of cell temperature decrement about 2.9 °C with increment of power generated by TE. Combined PV-TE was evaluated numerically [24], which showed the potential of cell temperature decrement for the proposed model and the ability to increase PV efficiency slightly (1.82%). Different work [25] conducted experimental process for TE concept as PV cooling method, showing the cell temperature drops by 3% with improvement in the system efficiency by 13.9%. Comprehensive numerical and experimental assessment [26] indicated that cascaded PV-TE offers higher cooling function with suitable power production, making the system ideal for alternative PV-TE assembly. Nevertheless, employing TE is still in development phase since the net produced power is insignificant (less than 5%) [27]. Therefore, effort to maximize the potential of waste heat from PV while simultaneously reducing the system temperature is still developed to achieve a more feasible method.

The produced heat from PV can be harvested and stored to material with heat storage capability such phase change materials (PCM). It can store the heat under certain working temperature [28–30]. A. Hamada et al. investigated PV-thermal (PVT) with PCM, indicating the cumulative achievement of system efficiency using passive PVT-PCM reached 74.1%, which was higher than system with no PVT at 34.6% [31]. Advance modification was taken with nano-PCM, which improved thermal efficiency and electrical power by 83.3% and 44.5% [32]. Optimization for the PVT-PCM was done by incorporating composite material, showing reliable improvement for continuous operation of the system for suitable regions [33]. Moreover, a different model was studied numerically to accommodate different heat transfer from the surface. This work [34] employed dual PCM as passive heat management for PV modules. Numerical modeling demonstrated a significant achievement in the efficiency (35.8%). In general, positive achievement is obtained by integrating system with PCM.

Employing PCM offers reliability of the application PVT. The PCM is used as alternative storage medium. However, the system demands additional equipment to harvest the stored heat, which requires supplementary equipment for the operation. Also, thermodynamic limits come as serious barrier due to maximum temperature generated by PV surface. Thus, waste heat from PV might be used directly rather than stored in different mediums. It is also suitable for the current trend of utilizing PV heaters for heat generation, particularly for rich electricity regions [35]. A. Szajding et al. analyzed high capacity PV-heating system, indicating simplification operation for heat generation purpose using PV [36]. Optimization was done to adjust the suitable operating condition for hot water supply from PV system based on specific household demands [37]. Therefore, it is advisable to harvest heat from PVT, which can be combined with the PV-heating concept.

The possibility of employing PV-heating with waste heat accumulation as one combined system offers a new option for residential water heating development. Previous works imply that the system operates independently and is not considered one compact system. Thus, the present study proposes to evaluate the idea of combined PV-heating and waste heat accumulation. It is the main novelty of this work, which differs from previous studies. The work here focuses on harvesting waste heat from PV modules for hot water production by placing thermal collector (TC) at the BS area and simultaneously connecting the PV output to electric heater. As a result, compact PVTC (photovoltaic-thermal collector) is obtained as one robust assembly. Therefore, the objective is designed to introduce and provide preliminary evaluation of the operation of PVTC for hot water production. The mass flowrate (MF) and filler material (FM) of the TC are varied to understand the impact of the given aspect on the accumulated energy of the system. The temperature, electrical output, and accumulated energy are presented and discussed briefly to provide new perspective on the

development of this concept. We believe it offers significant contribution for the development of residential water heating and potentially maximizing the utilization solar energy for the sector.

MATERIALS AND METHODS

Manufacturing PVTC Unit

The specification of PV module is presented in Table 1. TC unit is an additional component placed at the BS surface of PV assembly. Locating the TC in the given region is aimed to absorb heat and transferring it to the cold water. The process causes cooling effect for PV cells at the surface area. In this work, TC unit was equipped with serpentine copper tube (OD/ID: 6.35 mm/5.23 mm) as coolant path. The serpentine form is chosen for its suitable performance [38] and technical simplicity.

Figure 1a shows the photograph of the serpentine tube. There is empty space between each pass which makes the assembly required FM. Considering actual implementation, the FM must be widely available, have excellent technical properties, and be economically feasible. Thus, this work employed sand and grease as FM for the TC assembly. Sand is taken as solid filler with an excellent nature conductivity compared to water [39–41], making it favorable to fill the

Table 1. Specification of PV modules

Model	50 Wp monocrystalline PV
Dimension (mm)	670 × 410 × 30
V_{mp} (Volt)	18.0
I_{mp} (Ampere)	2.78
V_{oc} (Volt)	22.4
I_{sc} (Ampere)	3.24

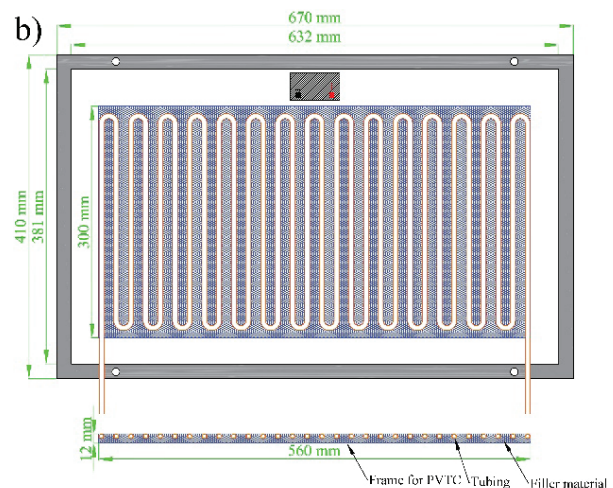


Figure 1. a) Photograph of serpentine tube and b) Dimension of the PVTC unit.

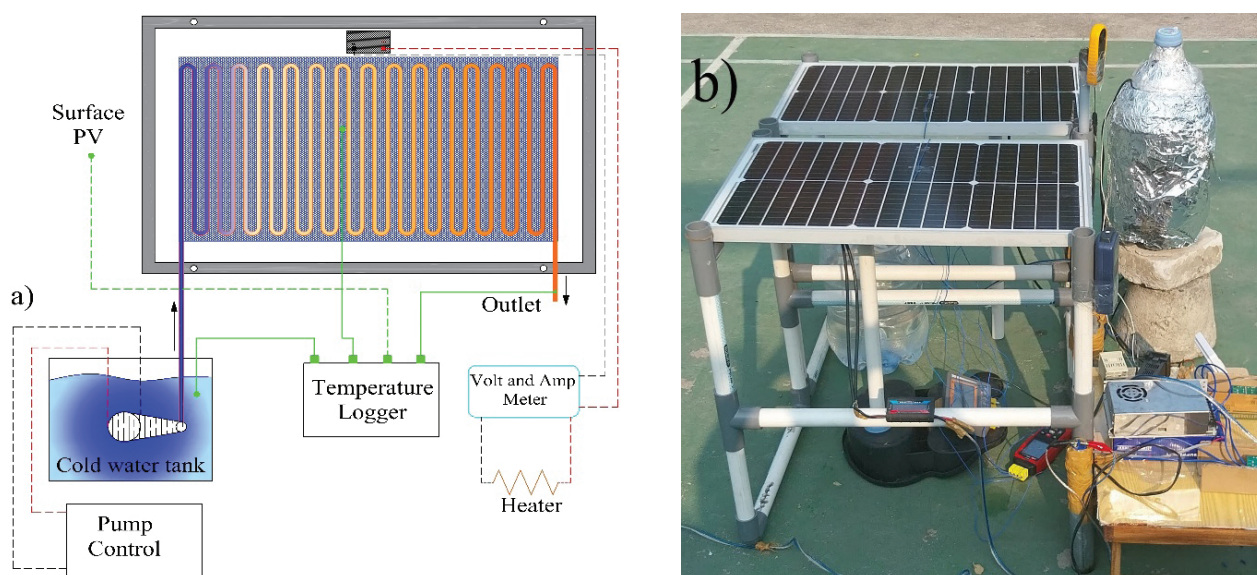


Figure 2. a) Schematic of the assessment and b) Photograph of the process.

empty space of the TC assembly. Sand with average mesh size 18 was used to maximize the filling ratio. Another FM for this work was thermal grease, which offers suitable contact area between each tube and BS layer [42]. In this work, grease class NLGI grade 2 was employed for the FM.

The detailed dimension of PVTC assembly is presented in Figure 1b. All component is placed in specifically designed frame made of acrylic. The tube was installed precisely to ensure direct contact with BS layer. The inlet/outlet tube was extended to accommodate the installation of additional hose for the working fluid. The system was examined for potential leakage and then installed at the BS layer to obtain one compact component as a PVTC.

Experimental Test

The assessment was conducted to observe the power output from PV and the amount of collected heat from TC. The schematic evaluation process is illustrated in Figure 2a. Cold water was distributed through TC assembly and collected heat from BS surface. Cold water temperature was maintained at 31 °C (± 1 °C). The temperature increment of the water after passing TC assembly was measured to

determine the input energy from TC. The SUT and BS temperature (BST) were recorded simultaneously during experiment. The PV was connected to heater, and the amount of produced electrical energy was recorded by I-V meter. The heater was placed in insulated storage with 7 liters of fresh water. The heated water was also measured throughout the process. Figure 2b shows the pictorial view of experimental process.

The evaluation was performed according to the variation of FM and MF of cold water. The designed name for each model is summarized in Table 2. Two systems were assessed simultaneously during each case. It was performed on October 2024 in West Java, Indonesia. The evaluated model, as presented in Table 2, is expected to provide additional information regarding the effect of FM and MF on the accumulated energy of system. Additionally, PVTC-SG was designed as mixture of sand/grease with ratio 75/25 (by volume) to observe the potential of the combined version of the two fillers.

On-field measurement was performed based on the schematic presented in Figure 2. The process was conducted

Table 2. Specific test model for evaluated system

System Name	Filler Material	MF ($\times 10^{-3}$ l/s)	Designated Case	Date
PVTC-S	Sand	4	Case 1	06/10/2024
PVTC-G	Grease	4		
PVTC-SL	Sand	2	Case 2	08/10/2024
PVTC-SG	Sand/Grease	2		
PVTC-SH	Sand	6	Case 3	10/10/2024
PV	-	-		

Table 3. Measurement properties of weather and apparatus

Aspect	Properties	Device	Accuracy	Range error (%)
Local weather	Solar radiation	SM206	0.1	5
	Air speed	UT363	0.1	3.5
	RH	HTC-2	1	8
	Air temperature		0.1	6
PV	Current	DC-150A	0.01	6
	Voltage			6
System	Temperature	Thermocouple (K)	0.1	2.2

from 08 AM to 03 PM (local time). As seen in Table 2, each test was taken at intervals one day due to weather condition on subsequent days. The local weather condition and all measurement equipment used in this work are summarized in Table 2. Each component has range error to indicate the uncertainty range from the measurement.

RESULTS AND DISCUSSION

Weather Conditions

The weather measurement was performed for each case since it affects the obtained result for evaluating the system (Table 2). The solar radiation profile (Fig. 3a) shows that peak radiation above 1000 W/m^2 occurs between 10:50–12:30. The average radiation for all cases is obtained between $769 - 827.2 \text{ W/m}^2$ with maximum radiation at 1273, 1178.5 and 1267 W/m^2 for evaluation at case 1, case 2 and case 3, respectively. The radiation values demonstrate the average condition for clear sky with intensity above 1000 W/m^2 [43]. The recorded air speed is considerably low during the test, with an average air speed less than 1 m/s .

Another weather parameter is ambient air temperature and RH (Fig. 3b). The average temperature for all cases ranges around $35.9 - 37.7^\circ\text{C}$, with peak temperature appearing in the midday along with peak solar intensity. The air was relatively dry during the experiment, according to the recorded RH. Despite the variation, the lowest RH is $29 - 31\%$, with average value between $34.4 - 38.5\%$. The recorded weather condition provides essential information to understand the obtained performance for the tested PV and PVTC. Moreover, the dynamic condition emphasizes that the actual measurement shows significant variation, which is more relevant for actual evaluation than in lab measurement. The error measurement from the metering device presented in Table 3 is provided to give additional consideration regarding the value obtained from this assessment.

PV Module Temperature

The direct exposure from the sun to PV module elevates its SUT notably. Figure 4 shows the recorded SUT, which clearly emphasizes the high temperature condition of PV module during the operation. The accumulated heat

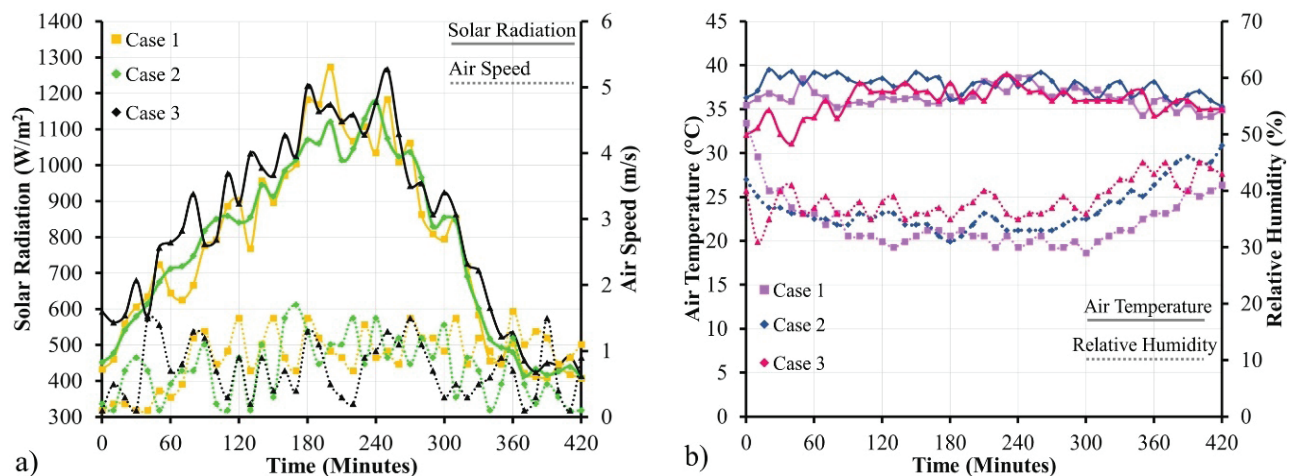


Figure 3. Weather condition on the experimental test: a) Solar radiation and air speed, and b) Air temperature and relative humidity.

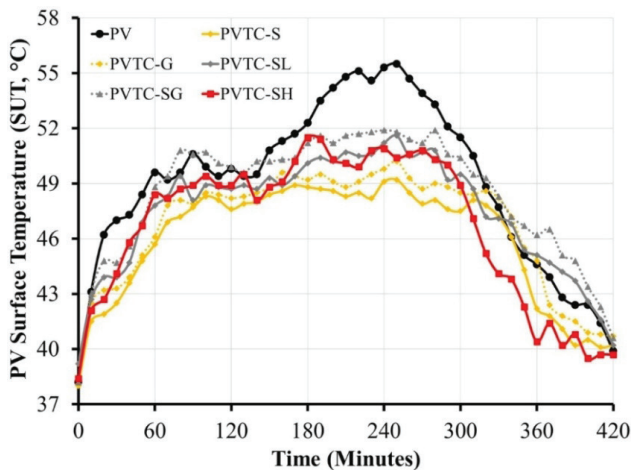


Figure 4. The SUT for all tested PV and PVTC assembly.

increases the SUT of PV module up to 55.5 °C with an average 49.1 °C. The specific increment in the initial operation is obtained at 4.7 °C/hour, then continues to increase steadily until the peak point at midday. The weather affects this high SUT, corresponding to the average ambient air temperature and low RH (Fig. 3b). The cooling effect from the ambient air is insufficient due to low air speed (Fig. 3a), making the average SUT higher (around 11.3 °C) than ambient temperature.

The presence of TC for the PVTC contributes positively to managing extreme SUT. The recorded SUT for PV modules decreases between 12.7–17.3% with TC. It confirms the benefit of using TC for PV, as it can achieve a lower SUT. Moreover, the FM plays different cooling effect for the PVTC system. PVTC with sand offers a higher heat dissipation from the PV module. It decreases the SUT by 8.8 °C (PVTC-S) and 9.6 °C (PVTC-SH). Lowering the MF for the same FM reduces the average heat dissipation around 8.1 °C. Moreover, the combined S/G for PVTC-SG has drawbacks due to the highest SUT (48.5 °C) among the other PVTC. In contrast, PVTC-G offers a relatively better SUT around 46.6 °C. The designed variation in this work shows relevant result to choose suitable FM and operating condition, making the aspects crucial to maximize the heat dissipation rate from PV modules.

The accumulated heat from the surface is transferred to the backsheet layer. As seen in Figure 5, the backsheet zone has remarkably high temperature, which is affected by the relatively thin layer assembly of typical PV modules [44]. Specifically for PV, the BST has identical temperature with the SUT, with average and maximum temperature of 46.7 °C and 55 °C. Adding additional TC effectively reduces the backsheet temperature, indicating a suitable cooling effect from the component. As observed, all cases show an optimum heat dissipation, which reduces the BST at lower temperature around 11.28–16.52% than PV.

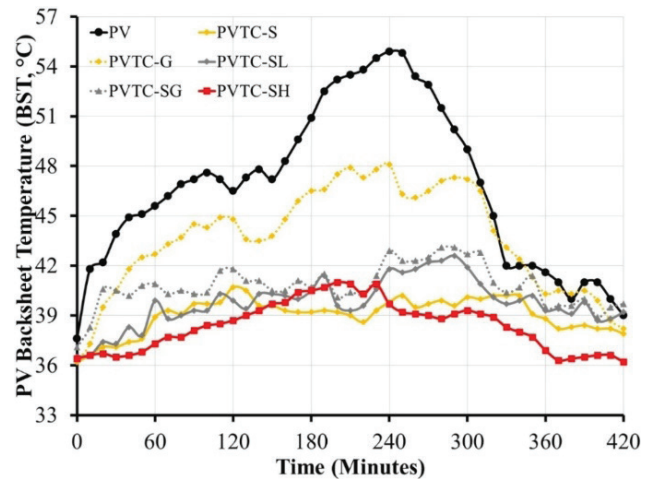


Figure 5. The BST for all tested PV and PVTC assembly.

Using different PVTC assembly directly affects the achievement of cooling effect for the BST. For example, PVTC with sand demonstrates suitable temperature decrement around 15.87% for PVTC-S. Modifying the MF for the same assembly (PVTC-SH) boosts the heat dissipation rate, reducing the temperature at relatively higher value (16.52%). It achieves the lowest recorded BST at 38.4 °C. Unfortunately, changing the filler with grease makes unfavorable cooling effect where the temperature at BST reduces only 11.3 °C relative to PV. It is minimized by adding sand (PVTC-SG), which can provide a higher heat dissipation, reducing the BST up to 14.2 °C even though it operates at lower MF. Regardless of the result, PVTC-G remains better at reducing the BST than PV without TC.

The ability to provide heat dissipation for the PVTC is observed according to the temperature deviation between SUT/BST (Fig. 6). PV has a lower gradient, indicating the heat transferred rapidly from surface to backsheet region.

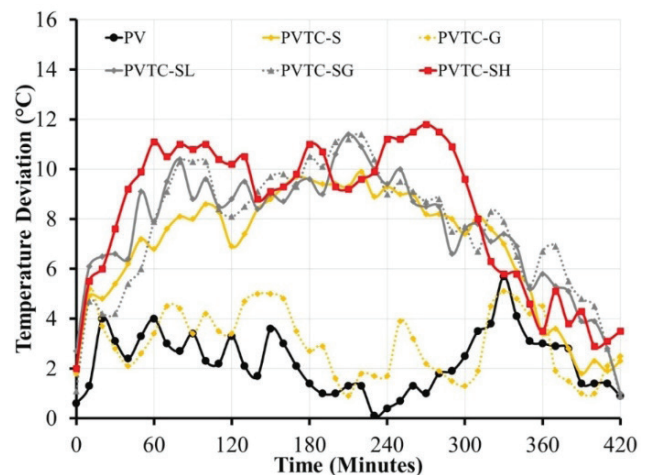


Figure 6. Temperature deviation between SUT/BST.

The low cooling effect for PVTC-G indicates the same behavior with average deviation of 3 °C, which varies insignificantly from PV (2.3 °C). Accordingly, it confirms the unsuitable heat dissipation rate, which might be affected by low conductivity of the grease. All PVTC with sand shows an excellent result, removing the heat effectively, which enhanced the temperature gradient between SUT/BST. The peak gradient is achieved by PVTC-SH (8.3 °C) and PVTC-S (6.9 °C). The low MF for PVTC-SL and PVTC-SG has similar value around 7.6 °C. The profile demonstrates the capability of the PVTC to reduce the BST, which eventually decreases the SUT (Fig. 4).

Generated Power from PV Module

The electric generation from PV occurs as unsteady process, as observed for the obtained V-curve in Figure 7a. It needs auxiliary component (charge controller) to maintain the steady voltage output. However, it comes with additional cost and potential power decrement [45]. Thus, the output PV is connected directly to the load to prevent additional power consumption and installation cost. Moreover, the heater is designed as the sole component that neglects voltage variation when generating heat. The plotted V-curve indicates the positive contribution of the addition of suitable PVTC configuration. The minimum voltage for PVTC increases around 7.4% (PVTC-S), 7.3% (PVTC-G), and 6.3% (PVTC-SH). According to [46], temperature increment results in a higher voltage drop. Thus, the obtained higher voltage for the PVTC demonstrates the positive contribution to temperature decrement of the module. However, exceptional result is observed for PVTC-SL and PVTC-SG, which indicates relatively identical value with PV. It is related to poor cooling effect for both systems. Additionally, external factors from weather conditions are also considered for this justification.

The I-curve is plotted in Figure 7b, showing more apparent implications on the impact of cooling effect on

the PV module. The obtained current for PV throughout the evaluation is 1.93 Ampere. It increases by 15.1% for PVTC-SH. Both systems were tested on the same day (Table 2), neglecting the weather factor and proving the positive achievement for implementing suitable PVTC. In addition, increment in the current is also achieved by PVTC-S (6.3%) and PVTC-SG (8.1%). It improves at relatively higher value for the PVTC-SL and PVTC-SG, approximately 10.6% and 12.3%.

The general representation of the conversion rate of the PV is observed according to the power map (Fig. 8). It is clear that PV is unable to achieve the designed maximum power capacity, which is affected by several conditions, such as soiling factor and weather condition [47]. Regardless of

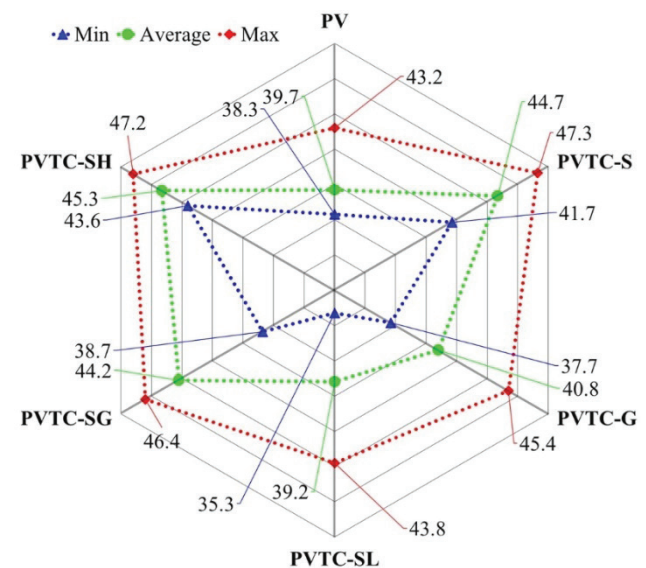


Figure 8. Power curve profile for all tested models.

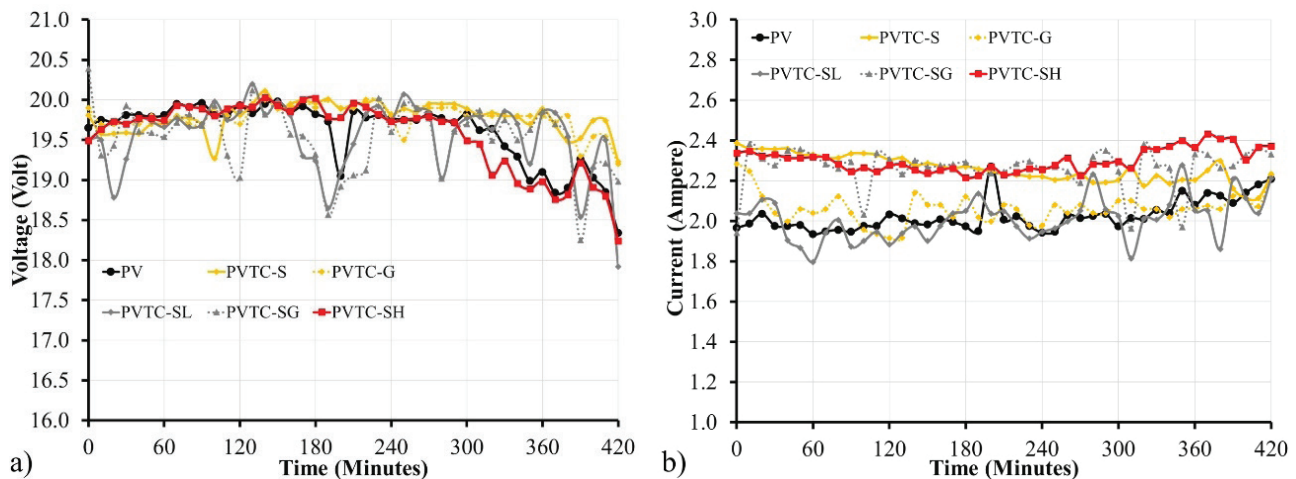


Figure 7. (a) V and (b) I curve for the tested PV and PVTC assembly.

the issue, positive achievement is generally demonstrated by the PVTC system, which consistently indicates a higher peak power. It is the main purpose to maintain the suitable SUT of PV module to ensure the effective power generation of the system [48]. Therefore, the evaluated PVTC in this work shows positive achievement in improving the power output of PV module.

Coolant and Heated Water Temperature

The specific role of employing different PVTC is shown according to the coolant outlet temperature (COT). Figure 9 presents that each model has variative COT profile, implying the specific role of the FM and operating condition based on the designed MF. PVTC-S shows a lower COT compared to PVTC-G. The average COT is 36.9 °C, while it increases about 3 °C for PVTC-G. It shows that PVTC-S has a more suitable heat dissipation behavior than PVTC-G, which supports the higher temperature gradient

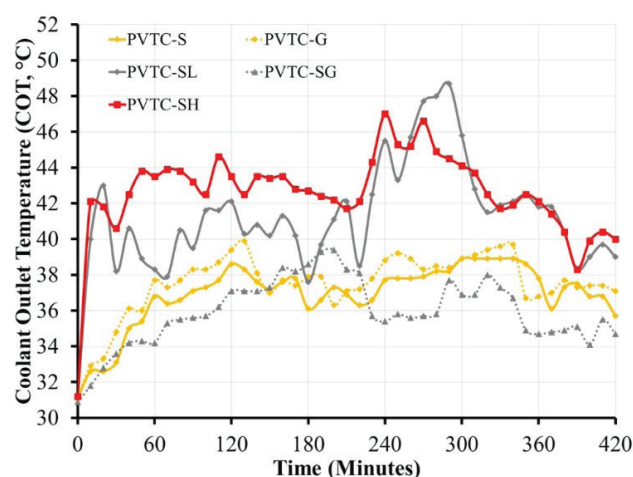


Figure 9. Characteristic of COT for the tested PVTC.

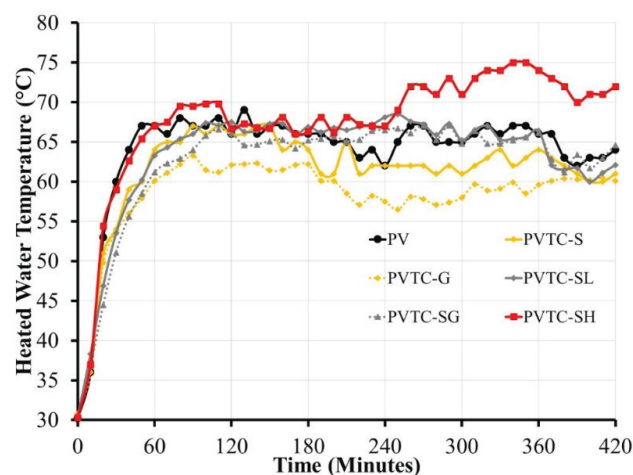


Figure 10. Characteristic of heated water from PV output.

for the PVTC-S (Fig. 6). In contrast, reducing the MF for PVTC-SG demonstrates steady profile, showing certain benefit for utilizing grease/sand mixture as FM for TC. It makes the COT maintain relatively constant value around 35.8 °C.

Utilizing sand at lower MF makes the COT fluctuate, causing severe temperature variation with maximum peak at 48.7 °C. However, the pattern indicates unreliable cooling behavior for the PV modules as this model obtains the lowest power among other PVTC (Fig. 8). Therefore, determination of suitable MF for the coolant is essential to ensure the optimum heat exchange process [49]. It is shown notably for the PVTC-SH using higher MF of the coolant. The COT increases steadily at the beginning before reaching its final peak at midday. In general, PVTC-SH achieves the highest average COT (42.6 °C) than the other model. It confirms the consistent temperature gradient of SUT/BST, as plotted in Figure 6.

The work focuses on the usability of PV output for heating process. The increment in the heated water temperature (Fig. 10) demonstrates the achievement of direct electric conversion for heating the water. It confirms that direct conversion is achievable, showing that the approach is reliable for storing surplus output from PV modules [50] and possibly combining it with renewable thermal system to enhance system efficiency [51]. The profile indicates the power characteristic for each tested model, which varies accordingly due to several factors. Moreover, direct outdoor measurement affects the probability of the variation results and the effective energy generated by PV for direct conversion. It can be combined with the power peak to track the net effective energy for the system (Fig. 8). Despite that, one positive achievement to provide lower temperature cell eventually leads to higher energy intake. It occurs for the PVTC-SH with maximum temperature 72 °C for the heated water.

The two water systems demonstrate the accumulated energy from the TC and PV. It confirms the key aspect of this work, which shows that the integrated PVTC is possible

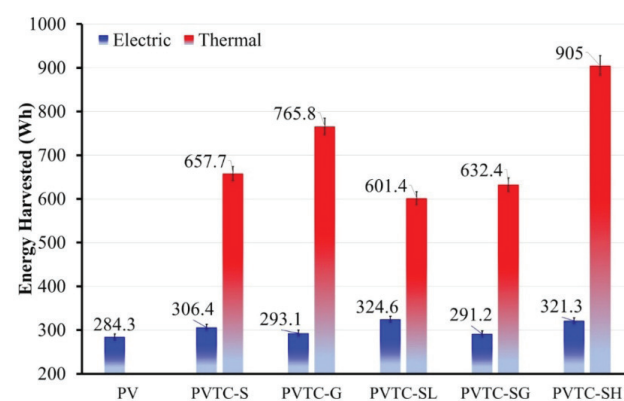


Figure 11. The accumulated electrical and heat energy input for all tested models.

to harvest heat in mutual process. The TC dissipates heat from the modules and stores it partially, while the process reduces the temperature of the PV module, resulting in higher power output. Moreover, the obtained heat from PV module is also applicable for charge operation of PCM [52]. Eventually, the approaches offer flexible storage model for PV system and enlarge the applicability to combine it with electric battery under specific consideration. The collected heat from the coolant adds more input energy, making the two processes produce higher energy density for one assembly PVTC system.

Accumulation of Energy from PVTC System

The PVTC system gains heat and electric energy simultaneously. The accumulated input is presented in Figure 11. The electrical energy from PV modules is lower than its designed maximum capacity, confirming the dynamic condition for on-field measurement, which is significantly affected by the weather conditions. Regardless of the condition, positive tendency is observed for PVTC system, which shows a higher electrical gain than PV. The maximum improvement is 14.2% and 13.1% for PVTC-SL and PVTC-SH. In the case of this condition, using grease as FM is less favorable due to insufficient heat dissipation, making the obtained electrical power relatively low (Fig. 8). It demonstrates suitable cooling behavior PV module promotes a higher power output, which makes the usability of sand as FM considered advantageous based on this finding.

One interesting result is that the system harvests more heat energy than the output electricity from PV module. It is the main challenge for implementing large PV system since the produced waste heat is higher than the generated electric power [53]. From practical perspective, it comes as a serious problem. However, if the system is also intended

for heat generation for water heating, the problem may be taken as additional advantage. According to TC operation, MF influences notably to harvest more heat energy from PV module, as observed for PVTC-SH, PVTC-SG, and PVTC-S. In general, all PVTC positively contribute to collecting the accumulated waste heat from PV module and taken as additional input energy from the assembly.

Figure 12 presents the gained energy from PV module as single component and system (PVTC). The value is obtained from the theoretical PV module output (50 Watts), which operated for 7 hours during the experimental process. PV module only generates electric energy with ratio 80.4%. All PVTC shows a higher value for the generated electricity, confirming the benefit of providing additional cooling mechanism for the PV module. Besides, PVTC also produces additional energy (heat) collected by the coolant. It promotes a positive contribution since the system offers a higher energy input from PV combined with TC, obtaining a higher cumulative energy harvested as a system.

CONCLUSION

The work assesses the PV system operation integrated by active cooling system with thermal collector. The system is operated for specific heating application, accumulating the output from PV and the collected heat from cooling system. The finding reveals that the concept is applicable with two benefits: improving the PV output by reducing the cell temperature and simultaneously harvesting waste heat as input energy for heating system. The cooling system reduces the PV temperature to 40.7 °C and offers maximum coolant output 48.7 °C. The collector is filled with sand and grease, showing significant contribution regarding the cooling ability which corresponds to their physical properties. Also, coolant flowrate plays crucial role in obtaining maximum cooling capacity and temperature output, making additional adjustment can be set according the requirement. PV and thermal collector produce higher cumulative energy around 1.23 kWh, while PV as single component only generates 0.28 kWh. Therefore, this point shows a notable energy output from the combined system.

The system (PV and thermal collector) offers a reliable energy output specifically designed for water heating. It allows the system to reach energy output 350.4% higher than the designed power output of the PV module in this work. However, this preliminary study is designed as an introductory for combined PV-thermal collector water heating. Thus, further work is required to assess in detail about reliability of the system for long term operation, including the possibility of introducing different filler material. Another crucial aspect is net energy balance for operating the pump and detailed techno-economy consideration. The finding from this work is suitable for taking as relevant baseline for further development of the PV-thermal collector for heating purpose, hoping for more advanced technology to maximize solar energy as a clean source for residential heating.

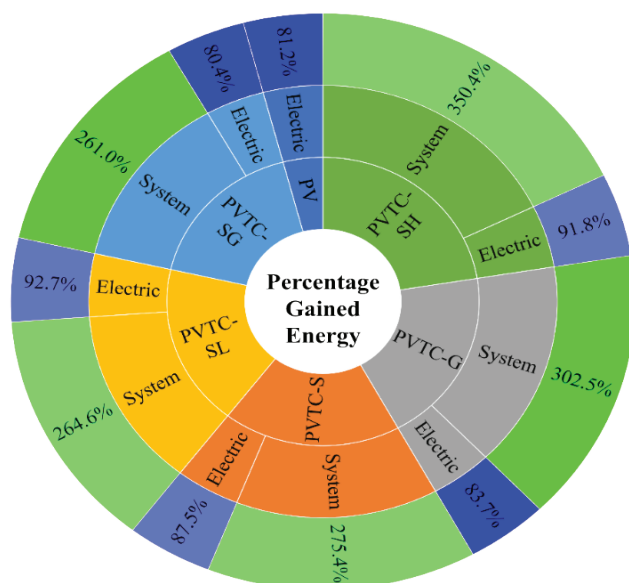


Figure 12. The Percentage of gained energy for all models.

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

STATEMENT ON THE USE OF ARTIFICIAL INTELLIGENCE

Artificial intelligence was not used in the preparation of the article.

REFERENCES

- [1] Tazhibayev SK, Alekseev AM, Aimukhanov AK, Ilyassov BR, Beisembekov MK, Rozhkova XS, et al. Influence of Spiro-Ometad film thickness on the structural and electrical properties of perovskite solar cells. *Eurasian Phys Tech J* 2024;21:23-34. [\[CrossRef\]](#)
- [2] Ismail A, Pane E, Abdu Rahman R. An open design for a low-cost open-loop subsonic wind tunnel for aerodynamic measurement and characterization. *HardwareX* 2022;12:e00352. [\[CrossRef\]](#)
- [3] Hari D, Prasetyo T, Sanata A, Sholahuddin I, Dimiyati M. Comprehensive analysis of tar reduction method in biomass gasification for clean energy production: a review. *Mech Eng Soc Ind* 2024;4:556-569. [\[CrossRef\]](#)
- [4] Obuseh E, Eyenubo J, Alele J, Okpare A, Oghogho I. A systematic review of barriers to renewable energy integration and adoption. *J Asian Energy Stud* 2025;9:26-45. [\[CrossRef\]](#)
- [5] Motlagh AA, Havaeji S, Orangian M, Samadani A. Achieving net-zero energy buildings: analyzing and optimizing strategies using sensitivity analysis. *J Asian Energy Stud* 2024;8:51-67. [\[CrossRef\]](#)
- [6] Jaddoa AA, Mahmoud MM, Karema AH. On assessing the effectiveness of hybrid solar collectors scheme in Iraq's environment. *Eurasian Phys Tech J* 2023;20:57-64. [\[CrossRef\]](#)
- [7] Yadav JS, Korakana S, Rao CM. Mini cold storage using the parabolic solar trough: an appropriate technology for perishable agricultural product. *Mech Eng Soc Ind* 2022;2:35-41. [\[CrossRef\]](#)
- [8] Eldokaishi AO, Abdelsalam MY, Kamal MM, Abotaleb HA. Modeling of water-PCM solar thermal storage system for domestic hot water application using artificial neural networks. *Appl Therm Eng* 2022;204:118009. [\[CrossRef\]](#)
- [9] Ismail A, Syahbana MSL, Rahman RA. Thermal performance assessment for an active latent heat storage tank by using various finned-coil heat exchangers. *Int J Heat Technol* 2022;40:1470-1477. [\[CrossRef\]](#)
- [10] Sadiq IE, Aljabair S, Karamallah AA. Accelerated solidification of PCM via Al₂O₃/CuO hybrid nanoparticles in triplex tube heat storage. *J Therm Eng* 2024;10:880-903. [\[CrossRef\]](#)
- [11] Yildiz B, Bilbao JI, Roberts M, Heslop S, Dore J, Bruce A, et al. Analysis of electricity consumption and thermal storage of domestic electric water heating systems to utilize excess PV generation. *Energy* 2021;235:121325. [\[CrossRef\]](#)
- [12] Yildiz B, Roberts M, Bilbao JI, Heslop S, Bruce A, Dore J, et al. Assessment of control tools for utilizing excess distributed photovoltaic generation in domestic electric water heating systems. *Appl Energy* 2021;300:117411. [\[CrossRef\]](#)
- [13] Olmuş U, Güzelel YE, Çerçi KN, Büyükalaca O. Effect of operating parameters on the performance of rotary desiccant wheel energized by PV/T collectors. *J Therm Eng* 2023;9:988-997. [\[CrossRef\]](#)
- [14] Khan A, Shahzad N, Waqas A, Mahmood M, Ali M, Umar S. Unlocking the potential of passive cooling: a comprehensive experimental study of PV/PCM/TEC hybrid system for enhanced photovoltaic performance. *J Energy Storage* 2024;80:110277. [\[CrossRef\]](#)
- [15] Elsheniti MB, Zaheer S, Zeitoun O, Fouly A, Abdo HS, Almutairi Z. An experimental assessment of a solar PVT-PCM thermal management system in severe climatic conditions. *J Build Eng* 2024;97:110691. [\[CrossRef\]](#)
- [16] Attia MEH, Kabeel AE, Khelifa A, Abdel-Aziz MM. Thermal and electrical analysis of the performance of a skeleton-shaped tubes via hybrid PVT cooling system. *Appl Therm Eng* 2024;248:123277. [\[CrossRef\]](#)
- [17] Chen H, Zhang J, Shen M, Fang H, Ma Y. Comprehensive numerical modeling of intermittent flow cooling with enhanced photovoltaic efficiency in PVT/NPCM systems. *Case Stud Therm Eng* 2024;58:104420. [\[CrossRef\]](#)
- [18] Wang Q, Yu C, Li T, Wang J, Liu Y, Shi Y, et al. Enhancing the performance of PVT-TEG power generation systems by heat pipes and Fe₃O₄ nanofluids. *Energy Convers Manag* 2024;319:118938. [\[CrossRef\]](#)

- [19] Madhi H, Aljabair S, Imran AA. A review of photovoltaic/thermal system cooled using mono and hybrid nanofluids. *Int J Thermofluids* 2024;22:100679. [\[CrossRef\]](#)
- [20] Madhi H, Aljabair S, Imran AA. Comparative numerical study on the effect of fin orientation on the photovoltaic/thermal (PV/T) system performance. *Int J Thermofluids* 2024;24:100909. [\[CrossRef\]](#)
- [21] Melaibari AA, Abu-Hamdeh NH, Alorfi AS, AL-bonsrulah HAZ, Elsiddieg AMA. New design for PVT system with elliptic cooling duct involving nanofluid in existence of MHD and utilizing TEG. *Case Stud Therm Eng* 2024;53:103815. [\[CrossRef\]](#)
- [22] Song Z, Zhang Y, Ji J, Wang C. Analysis of night behavior and negative running for PVT system. *Energy* 2024;301:131555. [\[CrossRef\]](#)
- [23] Selimefendigil F, Okulu D, Oztop HF. Three dimensional numerical study of PV module cooling by using thermoelectric effects and nano-enhanced confined multiple slot jet impingement. *Int J Heat Mass Transf* 2024;221:125093. [\[CrossRef\]](#)
- [24] Mahmoud AL, Shurafa S, Ismail FB, Kazem HA, Ee Sann T, Almajali TH. Enhancing photovoltaic-thermoelectric generator (PV-TEG) system performance via mathematical modeling and advanced thermal interface material: an emphasis on pyrolytic graphite sheet (PGS). *Sol Energy* 2024;273:112514. [\[CrossRef\]](#)
- [25] Widodo Besar Riyadi T, Effendy M, Radiant Utomo B, Tri Wijayanta A. Performance of a photovoltaic-thermoelectric generator panel in combination with various solar tracking systems. *Appl Therm Eng* 2023;235:121336. [\[CrossRef\]](#)
- [26] Rjafallah A, Cotfas DT, Cotfas PA. Investigation of temperature variations across the hot and cold sides of cascaded thermoelectric generator (CTEG) configurations in PV-CTEG hybrid systems. *Case Stud Therm Eng* 2024;61:105070. [\[CrossRef\]](#)
- [27] Nuwayhid RY, Rahal MS, Makarem YZ, Achkar RR. Thermal analysis of photovoltaic-thermoelectric hybrids. *J Therm Eng* 2024;10:1149-1163. [\[CrossRef\]](#)
- [28] Gharde PR, Havaladar SN. Numerical investigation of an amalgamation of two phase change materials thermal energy storage system. *J Therm Eng* 2022;10:263-272. [\[CrossRef\]](#)
- [29] Khademi A, Favakeh A, Darbandi M, Shafii MB. Numerical and experimental study of phase change material melting process in an intermediate fluid. *7th Int Conf Energy Res Dev ICERD* 2019:16-23.
- [30] Ode L, Firman M, Rahmalina D, Rahman RA. Hybrid energy-temperature method (HETM): A low-cost apparatus and reliable method for estimating the thermal capacity of solid-liquid phase change material for heat storage system. *HardwareX* 2023;16:e00496. [\[CrossRef\]](#)
- [31] Hamada A, Emam M, Refaey HA, Moawed M, Abdelrahman MA. Investigating the performance of a water-based PVT system using encapsulated PCM balls: an experimental study. *Energy* 2023;284:128574. [\[CrossRef\]](#)
- [32] Bassam AM, Sopian K, Ibrahim A, Al-Aasam AB, Dayer M. Experimental analysis of photovoltaic thermal collector (PVT) with nano PCM and micro-fins tube counterclockwise twisted tape nanofluid. *Case Stud Therm Eng* 2023;45:102883. [\[CrossRef\]](#)
- [33] Tashtoush B, Al Ghadi M. Optimization of energy output from PVT-PCM systems with emerging metal-organic frameworks phase change materials. *Heliyon* 2025;11:e42182. [\[CrossRef\]](#)
- [34] Sheikh Y, Jasim M, Qasim M, Qaisieh A, Hamdan MO, Abed F. Enhancing PV solar panel efficiency through integration with a passive multi-layered PCMs cooling system: a numerical study. *Int J Thermofluids* 2024;23:100748. [\[CrossRef\]](#)
- [35] Clift DH, Stanley C, Hasan KN, Rosengarten G. Assessment of advanced demand response value streams for water heaters in renewable-rich electricity markets. *Energy* 2023;267:126577. [\[CrossRef\]](#)
- [36] Szajding A, Kuta M, Cebo-Rudnicka A, Rywotycy M. Analysis of work of a thermal energy storage with a phase change material (PCM) charged with electric heaters from a photovoltaic installation. *Int Commun Heat Mass Transf* 2023;140:106547. [\[CrossRef\]](#)
- [37] Draou M, Brakez A. Multi-objective optimization of a diverter-driven photovoltaic water heater: a residential case study in Morocco. *Appl Therm Eng* 2024;242:122500. [\[CrossRef\]](#)
- [38] Olmuş U, Güzelel YE, Çerçi KN, Büyükalaca O. Numerical analysis and comparison of different serpentine-based photovoltaic-thermal collectors. *Renew Energy* 2025;241:122196. [\[CrossRef\]](#)
- [39] Zeng S, Yan Z, Yang J. An improved model for predicting the thermal conductivity of sand based on a grain size distribution parameter. *Int J Heat Mass Transf* 2023;207:124021. [\[CrossRef\]](#)
- [40] Suyitno BM, Rahmalina D, Rahman RA. Increasing the charge/discharge rate for phase-change materials by forming hybrid composite paraffin/ash for an effective thermal energy storage system. *AIMS Mater Sci* 2023;10:70-85. [\[CrossRef\]](#)
- [41] Liu X, Gao Y, Li Y. Estimating the thermal conductivity of unsaturated sand. *Appl Sci* 2024;14:36373. [\[CrossRef\]](#)
- [42] Francisco B, Nelson S, Jaakko E, Hatef M. Empirical investigation of solar photovoltaic-thermal collectors for heat pump integration. *Appl Therm Eng* 2024;248:123175. [\[CrossRef\]](#)
- [43] Srimanickam B, Kumar S. Drying investigation of coriander seeds in a photovoltaic thermal collector with solar dryer. *J Therm Eng* 2023;9:659-668. [\[CrossRef\]](#)

- [44] Sharma DK, Rathod MK, Bhale PV. Enhancement in thermal and electrical characteristics of solar photovoltaic module through a direct contact water jacketed cooling system. *J Therm Eng* 2023;10:360-374. [\[CrossRef\]](#)
- [45] Rahman RA, Sulisty S, Utomo MSKTS, Ragil D, Suyitno BM. Experimental evaluation on the power characteristic of direct-photovoltaic charging for thermal storage equipment. *Mech Eng Soc Ind* 2024;4:115-122. [\[CrossRef\]](#)
- [46] Hossain R, Ahmed AJ, Islam SMKN, Saha N, Debnath P, Kouzani AZ, et al. New design of solar photovoltaic and thermal hybrid system for performance improvement of solar photovoltaic. *Int J Photoenergy* 2020;2020:8825489. [\[CrossRef\]](#)
- [47] Akkoyunlu MT, Abdallatif Y. A comprehensive investigation of solar panel cleaning technologies: a review study. *J Therm Eng* 2024;10:1715-1741. [\[CrossRef\]](#)
- [48] Kayabaşı R, Kaya M. Effect of module operating temperature on module efficiency in photovoltaic modules and recovery of photovoltaic module heat by thermoelectric effect. *J Therm Eng* 2023;9:191-204. [\[CrossRef\]](#)
- [49] Xu Z, Sheng X, Chen J, Chen Y, He J, Luo X, et al. Industrial-grade hydrated salt-based PCM thermal energy storage device: thermal and economic performances. *Appl Therm Eng* 2025;262:125233. [\[CrossRef\]](#)
- [50] Hachchadi O, Tapsoba GR, Dery P, Mechaqrane A, Bourbonnais M, Meloche P, et al. Experimental optimization of the heating element for a direct-coupled solar photovoltaic water heater. *Sol Energy* 2023;264:112037. [\[CrossRef\]](#)
- [51] Pardillos-Pobo D, González-Gómez PA, Laporte-Azcué M, Santana D. Thermo-economic design of an electric heater to store renewable curtailment in solar power tower plants. *Energy Convers Manag* 2023;297:117710. [\[CrossRef\]](#)
- [52] Rahman RA, Sulisty S, Utomo MSKTS, Putra RDD. The optional approach in recycling plastic waste for energy storage application: a detailed evaluation of stabilized-hexadecanoic acid/plastic. *Case Stud Chem Environ Eng* 2024;9:100751. [\[CrossRef\]](#)
- [53] Wang F, Li Z, Liu M, Liu X, Pang D, Du W, et al. Heat-dissipation performance of photovoltaic panels with a phase-change-material fin structure. *J Clean Prod* 2023;423:138756. [\[CrossRef\]](#)