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Assessment of Electrical Energy Demand for Water Heating and Performance Optimization Using Photovoltaic Panels

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تقييم الطلب على الطاقة الكهربائية لتسخين المياه وتحسين الأداء باستخدام الألواح الكهروضوئية

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Abstract:
Hot water plays a vital role in numerous human and industrial applications, yet its production is often associated with significant environmental impacts. This growing demand underscores the importance of sustainable alternatives. Solar energy, as a clean and renewable resource, has emerged as a promising solution to mitigate these environmental effects. Libya, with its abundant solar radiation and favorable climatic conditions, offers an optimal setting for harnessing solar energy to generate electricity for water heating purposes. This paper presents calculating the number of photovoltaic (PV) panels required and the electrical energy generated to support water heating. The study was conducted in Brega, where solar irradiance reaches a peak intensity of 980 W/m², utilizing PV panels with an area of 1.65 m² installed at a tilt angle of 45°. The system design included a 40-liter water storage tank and was tested on June 15, 2024, over a 5-hour period. The results demonstrated encouraging feasibility, with the panels generating 1.2 kWh of electrical energy, while the thermal energy demand to heat the water was 1.4 kWh. These findings confirm that PV panels can serve as an effective and sustainable means for water heating, particularly in regions with high solar irradiance such as Libya. Future optimization of the system, including enhanced panel design and storage solutions, could further improve efficiency, making solar-powered water heating a viable alternative for both residential and industrial applications.

Keywords: Solar photovoltaic, Electricity generation, Heating water, Environment, Thermal energy.

الملخص
يلعب الماء الساخن دورًا حيويًا في العديد من التطبيقات البشرية والصناعية، ومع ذلك فإن إنتاجه غالبًا ما يرتبط بتأثيرات بيئية كبيرة. ويؤكد هذا الطلب المتزايد على أهمية إيجاد بدائل مستدامة. وقد ظهرت الطاقة الشمسية، باعتبارها مصدرًا نظيفًا ومتجددًا، كحل واعد للتخفيف من هذه التأثيرات البيئية. وتتمتع ليبيا بظروف مناخية مواتية وإشعاع شمسي وفير، مما يجعلها بيئة مثالية لاستغلال الطاقة الشمسية لتوليد الكهرباء من أجل تسخين المياه. تقدم هذه الورقة حساب عدد الألواح الكهروضوئية المطلوبة والطاقة الكهربائية المتولدة لدعم تسخين المياه. أُجريت الدراسة في منطقة البريقة، حيث يصل الإشعاع الشمسي إلى 980 واط/م²، باستخدام ألواح كهروضوئية تبلغ مساحتها 1.65 م² ومثبتة بزاوية ميلان قدرها 45 درجة. وشمل تصميم النظام خزان مياه بسعة 40 لترًا وتم اختباره في 15 يونيو 2024 على مدى فترة 5 ساعات. أظهرت النتائج جدوى مشجعة، حيث ولدت الألواح 1.2 كيلوواط ساعة من الطاقة الكهربائية، بينما كانت الطاقة الحرارية المطلوبة لتسخين المياه 1.4 كيلوواط ساعة. وتؤكد هذه النتائج أن الألواح الكهروضوئية يمكن أن تكون وسيلة فعالة ومستدامة لتسخين المياه، خاصة في المناطق ذات الإشعاع الشمسي العالي مثل ليبيا. ويمكن أن يؤدي تحسين النظام مستقبلاً، بما في ذلك تحسين تصميم الألواح وحلول التخزين، إلى تعزيز الكفاءة، مما يجعل تسخين المياه بالطاقة الشمسية بديلاً قابلاً للتطبيق في التطبيقات السكنية والصناعية.

الكلمات المفتاحية: الطاقة الشمسية الكهروضوئية؛ توليد الكهرباء، تسخين المياه، البيئة، الطاقة الحرارية.

Introduction

In the push toward creating positive energy buildings in the near future, the building envelope is, and will continue to be, a crucial player in energy generation [1-3]. Currently, buildings generate thermal or electrical energy efficiently using solar thermal collectors and photovoltaic (PV) panels integrated into their structure. These solar technologies thrive on well-oriented surfaces—typically those facing the equator. However, roof and facade areas with optimal orientation are limited, making it essential to maximize every available square meter for solar applications [4,5]. To achieve this, researchers are actively exploring innovative ways to develop and seamlessly integrate solar-active devices into building envelopes, driving new possibilities for sustainable, self-sufficient energy production [6-9].

Two primary categories of solar active devices can be integrated within the building envelope to facilitate energy production: solar thermal collectors, which harness solar radiation and convert it into usable thermal energy, and PV panels, which convert solar radiation directly into electricity. Despite the moderate conversion efficiency of PV cells, generally ranging between 10% and 20%, these cells exhibit high absorption across the solar radiation spectrum [10,11]. However, this high absorptive capacity results in the conversion of a substantial portion of the absorbed solar energy into heat. The consequent rise in cell temperature adversely impacts their performance by diminishing their overall energy conversion efficiency.

Approximately 90% of the incoming solar radiation is absorbed by PV cells, yet only around 15% is effectively converted into electricity. This leaves a vast potential for thermal energy recovery, as nearly 75% of the absorbed solar radiation remains untapped. To address this opportunity, the development of co-generation technologies, such as photovoltaic-thermal (PVT) collectors, presents a promising solution. These systems integrate PV cells with solar thermal absorbers, enabling the simultaneous generation of electricity and the efficient capture of excess heat, thereby optimizing the energy output from the same solar-collecting surface and enhancing overall system performance [12-16].

Numerous studies have been conducted on evaluating the electrical energy requirements for water heating and optimizing the performance of photovoltaic panel systems. Previous research [17] has characterized typical daily hot water consumption profiles for Australian households, providing insights into their energy demands. Studies reveal that the average household consumes 142 liters of hot water per day, corresponding to approximately 6 kWh of electricity usage. Additionally, typical daily electricity consumption profiles of domestic water heating systems have been established, highlighting patterns of energy usage. Research further indicates that excess electricity generation from a 4.5 kW photovoltaic (PV) system can meet 48% of the daily energy requirements for water heating.

According to [18], the present study provides a comprehensive numerical and experimental analysis of key parameters aimed at enhancing the heat transfer performance of photovoltaic thermal (PV/T) systems. The investigation focuses on the effects of flow dynamics, tube diameters, and base plate thickness on the thermal, electrical, and overall performance of water-based PV/T systems. The findings reveal that optimal performance is achieved when the system operates with a tube diameter of 16 mm and a water flow rate of 1.02 liters per minute. Under these conditions, the system exhibits an average thermal efficiency of 44.5%, electrical efficiency of 14.8%, and an overall efficiency of 59.3%, underscoring the potential for significant performance improvements through design optimization.

This paper contributes to the field of sustainable energy by providing a practical framework for evaluating the feasibility and efficiency of photovoltaic (PV) panels in water heating applications. Conducted in Brega, Libya—a region with abundant solar resources—the study offers valuable insights into system design and energy performance under real-world conditions. By calculating the number of PV panels needed and assessing the electrical energy generated to meet a 40-liter water heating demand, the research highlights the potential for leveraging solar energy as a sustainable alternative to conventional heating methods. The results demonstrate that two PV panels, each with an area of 1.65 m² and installed at a 45° tilt, can generate 1.2 kWh of electrical energy over a 5-hour period, covering most of the 1.4 kWh thermal energy requirement for heating water.

The Concept of Solar Energy

Solar energy refers to the radiant energy emitted by the sun, which reaches the Earth in the form of light and heat. The sunlight striking the Earth's surface represents a natural and renewable energy source with immense potential [19,21]. The availability and abundance of solar energy, combined with advancements in modern technologies, have positioned it as an increasingly attractive option for large-scale electricity generation and other sustainable applications [22-26]. Figure 1 illustrates water heating system.

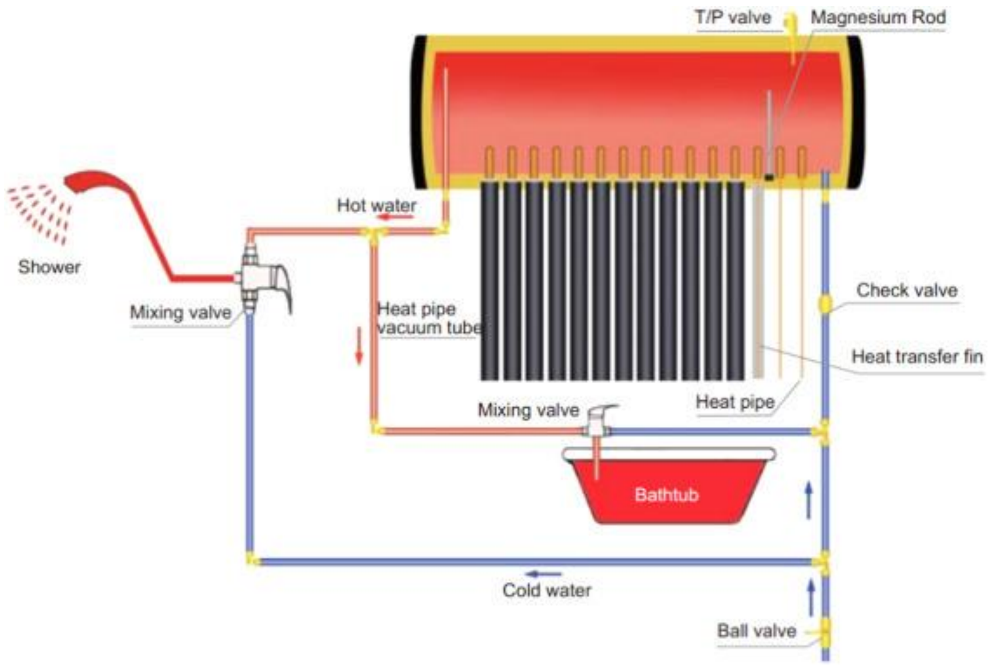

Figure 1. Water heating system.

This diagram illustrates the basic design and functionality of a solar water heating system that uses heat pipe vacuum tubes to transfer thermal energy for domestic water heating applications [27,28]. The major components and their roles are explained as follows:

Key Components and Functionality:

- Solar Collector (Heat Pipe Vacuum Tubes)

The vacuum tubes, arranged in parallel, are the core of the system. They consist of sealed glass tubes containing heat pipes and heat transfer fins that absorb solar radiation [29,30]. The vacuum between the inner and outer glass layers minimizes heat loss, making the system highly efficient. Inside each tube, sunlight heats the fluid within the heat pipes, which evaporates and rises to the manifold (the top horizontal container), where it transfers heat to the water stored inside the tank.

- Water Storage Tank

The insulated storage tank holds the heated water and maintains its temperature by minimizing heat loss. A magnesium rod is included inside the tank to prevent corrosion and protect the system's internal components through sacrificial anode protection [31,32].

- T/P Valve (Temperature/Pressure Relief Valve)

This safety valve automatically releases pressure or temperature buildup in the system, preventing overheating or excessive pressure that could damage the tank.

- Cold Water Inlet and Ball Valve

Cold water enters the system through the cold-water inlet, regulated by a ball valve, which controls the water supply. As cold water is fed into the system, hot water exits for household use.

- Mixing Valve

The mixing valve blends hot water from the storage tank with cold water to maintain a safe, comfortable temperature for end use. This ensures that water used in showers and bathtubs is not excessively hot.

- Hot Water Outlet

Heated water from the storage tank flows through the hot water outlet and into the home's plumbing system for use in bathing, cleaning, and other domestic purposes.

- Check Valve

This valve ensures that water flows in one direction, preventing backflow of hot water into the cold-water supply.

Working Principle:

The system works by capturing solar radiation through the vacuum tubes, which convert sunlight into heat. This heat is transferred to the working fluid inside the heat pipes, which then evaporates and carries the heat upward into the storage tank via the manifold [33-35]. The condensed fluid returns to the base of the tubes, repeating the cycle as long as solar energy is available. The thermal energy stored in the tank is then used for domestic purposes, providing an energy-efficient and environmentally friendly solution for water heating.

Efficiency Features:

- Vacuum insulation: Minimizes heat loss and enhances performance, especially in cooler environments.
- Heat pipe technology: Allows efficient heat transfer without the need for mechanical pumps.
- Mixing valve: Maintains user safety by regulating water temperature.
- Magnesium rod: Enhances system longevity by reducing corrosion risks.

Overall, this system provides sustainable hot water by utilizing solar energy, reducing dependency on conventional energy sources and lowering overall carbon emissions.

Mathematical Modeling

Table 1 represents the surface area of the solar collector (either photovoltaic panels or vacuum tubes) available to capture solar radiation. The larger the area, the greater the potential for solar energy absorption, which directly affects the system's energy generation and heat transfer rates. This value defines the amount of energy required to raise the temperature of 1 kg of water by 1 K (or 1 °C). The specific heat of water is relatively high, meaning it can store significant amounts of thermal energy, making it an ideal medium for heat transfer in solar water heating systems. Solar irradiance represents the power per unit area received from the sun. A value of 980 W/m² suggests relatively strong sunlight conditions, typical of regions with high solar potential. This parameter is a key input for calculating both thermal and electrical energy generation.

Table 1: Parameters of the system.

Parameters	Values	Unit
A	1.63	m2
Cp	4186	$j/kg.k$
G	980	W/m²
m	40	kg
t	5	hr
Pmax	250	w
μ_{pv}	15.37	%

The mass of water refers to the quantity of water being heated within the system at any given time. It directly affects the total heat energy required and influences the overall system efficiency, as larger volumes may require longer heating times depending on solar intensity and other parameters. The heating duration (5 hours) is critical in determining how much thermal energy the system can transfer to the water during the solar collection period. Longer durations may enhance heat gain, but efficiency can be reduced if environmental factors (e.g., shading, ambient temperature) affect performance. This indicates the peak electrical power the photovoltaic panels can generate under optimal conditions. It reflects the electrical contribution of the system, which could be used to support auxiliary systems, pumps, or even hybrid heating mechanisms. The value suggests a moderately sized PV array. This parameter defines the percentage of incoming solar energy that is converted into electrical power by the PV panels. A value of 15.37% is typical for commercial PV systems, indicating that the system can convert a fraction of the available solar energy into usable electricity, with the remainder primarily converted to heat.

- PV-Based Water Heating Systems

Photovoltaic (PV)-based water heating systems utilize solar energy by converting sunlight into direct current (DC) electricity through PV panels. This electricity powers resistive heating elements immersed in the water storage tank to generate heat. The key components of the system include:

  - PV Panels:

These are the primary components responsible for converting sunlight into electrical energy. Their performance depends on factors such as solar irradiance, panel efficiency, and temperature.

  - Resistive Heating Elements:

These elements convert the electrical energy generated by the PV panels into thermal energy, heating the water. The efficiency of this process typically approaches 100% due to the direct conversion of electrical energy into heat.

  - Controller:

The controller is essential for optimizing system performance by ensuring the maximum power output from the PV panels is efficiently delivered to the heating elements. It regulates the load to match the PV panel's power output under varying solar conditions. Moreover, the electrical energy output ($\boldsymbol{E_{el}}$) represents the total energy generated by the photovoltaic (PV) panel within a defined time interval. This parameter is determined using a mathematical formulation derived from the following considerations.
The power output per unit area of the panel is given by Eq.1.

$$P_{area} = \mu_{pv} \times G \qquad \text{(Eq.1)}$$

The total power output of the panel is given by Eq. 2.

$$P_{total} = P_{area} \times A \qquad \text{(Eq. 2)}$$

To calculate the energy output in Joules, multiply the power by the time in seconds. For example, over 5 hours (18,000 seconds):

$$E_{el} = P_{total} \times t \qquad \text{(Eq. 3)}$$

Eq. 4 presents thermodynamics for calculating heat transfer in fluids. It is referenced in the context of PV/T systems.

$$Q_{th} = m \times C_p \times \Delta T \qquad \text{(Eq. 4)}$$

The Eq. 5 calculates the thermal energy needed to heat water based on number of panels.

$$N = \frac{Q_{th}}{E_{el}} \qquad \text{(Eq. 5)}$$

With the corrected calculation, approximately 2 panels are needed to heat 40 liters of water by 30°C under STC. This is a more realistic and accurate result.

Results

To assess the system's performance, relevant data was systematically collected and presented in the table below. The primary objective of this evaluation was to analyze the efficiency of the solar panels in producing electrical energy and to quantify the electrical energy required for water heating. Furthermore, the amount of supplemental thermal energy needed from the water heater was calculated. This comprehensive analysis was conducted over a 5-hour period on 15 June 2024, under defined environmental and operational conditions. The results offer critical insights into the system's energy demands and its overall capability to effectively meet both thermal and electrical requirements. Table 2 illustrates the collected data encompasses time intervals, ambient temperature, and solar irradiance levels.

Table 2: The collected data encompasses time intervals, ambient temperature, and solar irradiance levels.

Time	Ti oc	Gt w/m2
10	20	600
11	30	700
12	35	980
13	32	750
14	26	650

Table 2 outlines the key data collected, including time, ambient temperature, and solar irradiance—parameters essential for evaluating the system's performance. These variables were meticulously recorded to investigate the relationship between environmental factors and the system's energy output. Ambient temperature represents the surrounding thermal environment, while solar irradiance measures the intensity of available sunlight for energy conversion. By analyzing the correlation of these parameters over time, the system's efficiency in capturing solar energy and its ability to meet energy demands under dynamic conditions can be effectively evaluated. This dataset offers a comprehensive perspective on the system's operational behavior and its adaptability to fluctuations in environmental conditions. Table 3 demonstrates explanation of the compiled results, detailing the system's performance metrics and collected data.

Table 3: Explanation of the compiled results, detailing the system's performance metrics and collected data.

Time (h)	Ti (oC)	Gt (w/m2)	P_{total} (w)	E_{el} (kw/h)	Q_{th} (kw/h)
10	20	600	148.5	0.7425	1.40
11	30	700	173.5	0.8675	0.39
12	35	980	242.5	1.2125	0.69
13	32	750	185.6	0.928	0.83
14	26	650	160.8	0.804	1.12

Table 3 provides a comprehensive analysis of the results derived from the previously collected data, revealing key insights into the system's performance. The findings indicate a direct and significant correlation between solar irradiance and the system's power output and electrical energy generation. As solar irradiance increases, the system demonstrates enhanced energy production, reflecting its efficiency in converting solar energy into electrical power. Conversely, thermal energy requirements exhibit an inverse relationship with both ambient temperature and solar irradiance. Elevated ambient temperatures reduce the need for supplementary thermal energy, as the system inherently retains more heat. Overall, the system demonstrates consistent and reliable performance, with its energy outputs closely responsive to environmental fluctuations, underscoring its efficiency and adaptability to varying operational conditions.

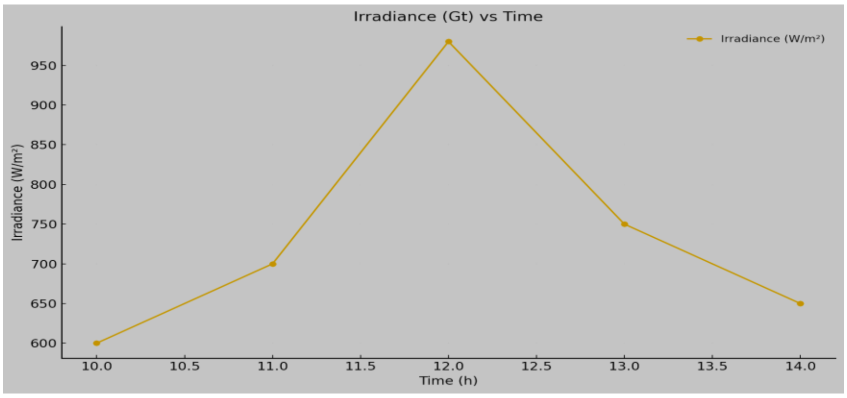

Figure 2: Temporal Variation of Solar Radiation Intensity.

Figure 2 presents the temporal variation of solar irradiance (G_t). The curve reveals a characteristic pattern where solar irradiance increases steadily during the morning hours, reaching its maximum intensity around solar noon (12:00), when the sun is at its zenith. Following this peak, irradiance gradually diminishes throughout the afternoon, exhibiting a typical diurnal trend inherent to solar energy systems. This behavior reflects the direct dependency of solar irradiance on the sun's position relative to the observer.

Figure 3 presents a comprehensive analysis of multiple variables influencing energy performance, highlighting the temporal relationships between solar irradiance, ambient temperature, total power output, and cumulative energy generation. The curves are explained as follows:

- Ambient Temperature (°C): Represented by the orange curve, this variable reflects the ambient temperature measured over the course of the day. The curve demonstrates a pronounced peak around 12:00, marking the warmest period of the day, typically aligned with maximum solar exposure.
- Solar Irradiance (W/m2): The red curve depicts the intensity of solar radiation per unit area. It mirrors the trend of ambient temperature, peaking at solar noon (12:00) when the sun is at its highest elevation, thus receiving the greatest solar flux.
- Total Power Output (W): Illustrated by the blue curve, this variable represents the total power generated by the system. The curve reveals a direct correlation with solar irradiance—higher irradiance results in increased power output, reaching its maximum during midday and decreasing as irradiance wanes.
- Electrical Energy Generation (kWh): The yellow curve tracks the cumulative electrical energy produced throughout the day. Beginning at a low level during early morning, it gradually rises

as power generation intensifies, before stabilizing in the afternoon when solar irradiance declines.

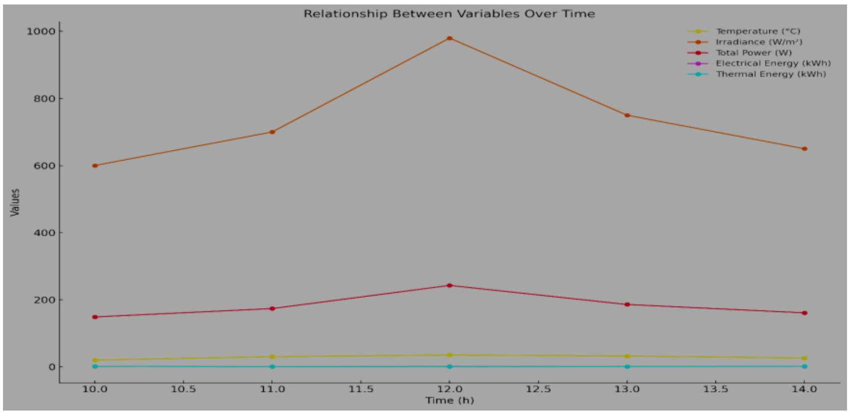

Figure 3: Temporal Variation of Solar Radiation Intensity, Power Output, Electrical Energy, and Thermal Energy.

- Thermal Energy Generation (kWh): Depicted by the green curve, this variable reflects the cumulative thermal energy output. Its trend closely resembles that of electrical energy, exhibiting a steady increase as power generation rises and leveling off as solar input diminishes later in the day.

The alignment of these curves highlights the critical influence of solar irradiance on both power and energy outputs, with the midday period serving as the peak operational window for maximum energy capture and system efficiency.

Discussion

Under Standard Test Conditions (STC), a single Solet P60.6 BF-250 photovoltaic panel is capable of generating approximately 1.2 kWh of electrical energy per day. This value serves as a baseline for evaluating system performance under varying conditions. In term of thermal energy demand, to heat 40 liters of water by 30°C, approximately 1.4 kWh of thermal energy is required. This demand forms a key parameter in the design and sizing of the integrated solar system for domestic or industrial heating applications. Based on the calculated thermal energy demand, it is estimated that two Solet P60.6 BF-250 panels are sufficient to meet the daily requirement for heating 40 liters of water. This estimation assumes optimal solar exposure and minimal system losses.

The system's performance rate, characterized by the rate of energy output, demonstrates a diurnal pattern. It gradually increases during the morning hours, peaks around midday when solar irradiance is at its maximum, and subsequently declines as the sun sets. This behavior is typical for photovoltaic and thermal systems dependent on solar input. The graphical analysis reveals strong interdependence between key system variables over time. Solar irradiance and ambient temperature show a pronounced correlation, both peaking around midday. Total power output closely follows the irradiance trend, reflecting the system's dependency on solar availability. The cumulative generation of electrical and thermal energy steadily increases during daylight hours, with a notable plateau as irradiance diminishes. These observations highlight the system's optimal performance during peak solar hours, suggesting that efficient energy management strategies should be implemented during this period to maximize output.

Conclusion

This study evaluated the feasibility of employing photovoltaic (PV) panels for water heating applications. The graphical analysis revealed a strong correlation between solar irradiance and ambient temperature, which directly impacts system performance. As solar irradiance increases, the power output rises proportionally, leading to a corresponding escalation in the generation of both electrical and thermal energy. The curves exhibit a distinct peak around 12:00, coinciding with maximum irradiance and temperature, signifying optimal system performance during peak solar hours. Utilizing a 1.65 m² Solet P60.6 BF-250 PV panel with a rated power output of 250 W, preliminary estimates indicate that approximately two panels are required to heat 40 liters of water by 30°C under typical conditions. This result highlights the system's promising efficiency for small-scale water heating applications. However, further system enhancements, such as implementing panel cooling techniques and hybrid configurations (e.g., integrating thermal and electrical subsystems), can significantly boost overall efficiency, potentially reducing the number of panels required. This study offers a foundational framework for the design and optimization of PV-based water heating systems, supporting the ongoing development of sustainable energy solutions. Future research could explore the impact of variable climatic conditions, system configurations, and energy storage integration to further improve system viability and scalability in diverse applications.

References

[1] M. López, F. Soto, and Z. A. Hernández, “Assessment of the potential of floating solar photovoltaic panels in bodies of water in mainland Spain,” *J. Clean. Prod.*, vol. 340, no. 130752, p. 130752, 2022.

[2] X. Hao, S. Shan, N. Gao, G. Chen, Q. Wang, and T. Gu, “Performance analysis of a novel combined cooling, heating and power system with solar energy spectral beam splitting,” *Energy Convers. Manag.*, vol. 276, no. 116500, p. 116500, 2023.

[3] P. Sudhakar, R. Santosh, B. Asthalakshmi, G. Kumaresan, and R. Velraj, “Performance augmentation of solar photovoltaic panel through PCM integrated natural water circulation cooling technique,” *Renew. Energy*, vol. 172, pp. 1433–1448, 2021.

[4] S. M. Shalaby, M. K. Elfakharany, B. M. Moharram, and H. F. Abosheiasha, “Experimental study on the performance of PV with water cooling,” *Energy Rep.*, vol. 8, pp. 957–961, 2022.

[5] M. Ghazy, E. M. M. Ibrahim, A. S. A. Mohamed, and A. A. Askalany, “Experimental investigation of hybrid photovoltaic solar thermal collector (PV/T)-adsorption desalination system in hot weather conditions,” *Energy (Oxf.)*, vol. 254, no. 124370, p. 124370, 2022.

[6] S. S. Bhakre, P. D. Sawarkar, and V. R. Kalamkar, “Performance evaluation of PV panel surfaces exposed to hydraulic cooling – A review,” *Sol. Energy*, vol. 224, pp. 1193–1209, 2021.

[7] Y. F. Nassar *et al.*, “Sensitivity of global solar irradiance to transposition models: Assessing risks associated with model discrepancies,” *e-Prime - Advances in Electrical Engineering, Electronics and Energy*, vol. 11, no. 100887, p. 100887, 2025.

[8] M. Khaleel, Z. Yusupov, A. Ahmed, A. Alsharif, Y. Nassar, and H. El-Khozondar, “Towards sustainable renewable energy,” *Appl. Sol. Energy*, vol. 59, no. 4, pp. 557–567, 2023.

[9] Y. F. Nassar *et al.*, “Thermoelectrical analysis of a new hybrid PV-thermal flat plate solar collector,” in *2023 8th International Engineering Conference on Renewable Energy & Sustainability (ieCRES)*, 2023.

[10] M. Khaleel, Z. Yusupov, N. Yasser, H. Elkhozondar, and A. A. Ahmed, “An integrated PV farm to the unified power flow controller for electrical power system stability,” *Int. J. Electr. Eng. and Sustain.*, pp. 18–30, 2023.

[11] P. Dupeyrat, C. Ménézo, and S. Fortuin, “Study of the thermal and electrical performances of PVT solar hot water system,” *Energy Build.*, vol. 68, pp. 751–755, 2014.

[12] S. Abdul-Ganiyu, D. A. Quansah, E. W. Ramde, R. Seidu, and M. S. Adaramola, “Study effect of flow rate on flat-plate water-based photovoltaic-thermal (PVT) system performance by analytical technique,” *J. Clean. Prod.*, vol. 321, no. 128985, p. 128985, 2021.

[13] A. Ghayth, Z. Yusupov, A. Hesri, and M. Khaleel, “Performance enhancement of PV array utilizing Perturb & Observe algorithm,” *Int. J. Electr. Eng. and Sustain.*, pp. 29–37, 2023.

[14] S. Shoeibi, M. Saemian, M. Khiadani, H. Kargarsharifabad, and S. Ali Agha Mirjalily, “Influence of PV/T waste heat on water productivity and electricity generation of solar stills using heat pipes and thermoelectric generator: An experimental study and environmental analysis,” *Energy Convers. Manag.*, vol. 276, no. 116504, p. 116504, 2023.

[15] Y. F. Nassar *et al.*, “Design of reliable standalone utility-scale pumped hydroelectric storage powered by PV/Wind hybrid renewable system,” *Energy Convers. Manag.*, vol. 322, no. 119173, p. 119173, 2024.

[16] M. Khaleel, A. A. Ahmed, and A. Alsharif, “Artificial Intelligence in Engineering,” *Brilliance*, vol. 3, no. 1, pp. 32–42, 2023.

[17] B. Yildiz *et al.*, “Analysis of electricity consumption and thermal storage of domestic electric water heating systems to utilize excess PV generation,” *Energy (Oxf.)*, vol. 235, no. 121325, p. 121325, 2021.

[18] A. Hassan *et al.*, “An experimental and numerical study on the impact of various parameters in improving the heat transfer performance characteristics of a water based photovoltaic thermal system,” *Renew. Energy*, vol. 202, pp. 499–512, 2023.

[19] S. Navakrishnan, E. Vengadesan, R. Senthil, and S. Dhanalakshmi, “An experimental study on simultaneous electricity and heat production from solar PV with thermal energy storage,” *Energy Convers. Manag.*, vol. 245, no. 114614, p. 114614, 2021.

[20] Y. F. Nassar *et al.*, “Regression model for optimum solar collectors’ tilt angles in Libya,” in *2023 8th International Engineering Conference on Renewable Energy & Sustainability (ieCRES)*, 2023.

[21] Y. Nassar *et al.*, “Solar and wind atlas for Libya,” *Int. J. Electr. Eng. and Sustain.*, pp. 27–43, 2023.

[22] M. Khaleel *et al.*, “Emerging issues and challenges in integrating of solar and wind,” *Int. J. Electr. Eng. and Sustain.*, pp. 1–11, 2024.

[23] F. Alasali, A. S. Saidi, N. El-Naily, O. Alsmadi, M. Khaleel, and I. Ghirani, “Assessment of the impact of a 10-MW grid-tied solar system on the Libyan grid in terms of the power-protection system stability,” *Clean Energy*, vol. 7, no. 2, pp. 389–407, 2023.

[24] Y. Nassar *et al.*, “Simulating the energy, economic and environmental performance of concentrating solar power technologies using SAM: Libya as a case study,” *jsesd*, vol. 12, no. 2, pp. 4–23, 2023.

[25] M. Khaleel *et al.*, “Evolution of emissions: The role of clean energy in sustainable development,” *Chall. Sustain.*, vol. 12, no. 2, pp. 122–135, 2024.

[26] M. Khaleel and M. Elbar, “Exploring the rapid growth of solar photovoltaics in the European Union,” *Int. J. Electr. Eng. and Sustain.*, pp. 61–68, 2024.

[27] M. A. Razig, A. E. Mohammed, and A. G. Khalifa, “Manufacturing of A solar desalination system,” *Int. J. Electr. Eng. and Sustain.*, pp. 19–26, 2024.

[28] Y. M. Othman Khaleel, M. A. M. Haweel, K. M. Saied, A. A. S. Gheidan, and A. J. Meelad, “Design of A single-cover solar collector to heat water for A typical building,” *Int. J. Electr. Eng. and Sustain.*, pp. 27–37, 2024.

[29] B. Bayhan and G. Arslan, “Experimental investigation of natural circulating solar energy system including a parabolic trough solar collector,” *J. Sol. Energy Eng.*, vol. 147, no. 2, 2025.

[30] M. Rahbari, P. Esfanjani, A. Mahmoudi, and M. S. Valipour, “Performance enhancement of a parabolic dish collector with a novel receiver assisted with a secondary reflector,” *Sol. Energy Mater. Sol. Cells*, vol. 283, no. 113464, p. 113464, 2025.

[31] X. Liu and K. Wei, “A method for calculating the design volume of the initial rainwater storage tank,” *Water Resour. Manage.*, vol. 39, no. 1, pp. 161–177, 2025.

[32] K. Huang, H. Lin, G. Feng, A. Li, H. Xie, and J. Wei, “Experimental and numerical thermal performance analysis of a phase change water tank with S-shaped channel,” *J. Energy Storage*, vol. 108, no. 114840, p. 114840, 2025.

[33] S. Van Minnebruggen, H. Matbouli, S. Jacobs, and I. Verhaert, “In-situ validation of a sizing method for the combined production and distribution of heat for space heating and domestic hot water,” *J. Build. Perform. Simul.*, vol. 17, no. 4, pp. 443–459, 2024.

[34] A. Maraj, A. Londo, C. Firat, and A. Gebremedhin, “Comparison of the energy performance between flat-plate and heat pipe evacuated tube collectors for solar water heating systems under Mediterranean climate conditions,” *J. Sustain. Dev. Energy Water Environ. Syst.*, vol. 7, no. 1, pp. 87–100, 2019.

[35] A. A. Khadom, H. B. Mahood, A. A. Mahmmod, Q. Hassan, and H. A. Kazem, “Improving solar water heating performance and reducing emissions by evacuated tube collectors with preheating units: Iraq as a case study,” *Appl. Therm. Eng.*, vol. 265, no. 125596, p. 125596, 2025.