Future Technology
Open Access Journal
ISSN 2832-0379

February 2025| Volume 04 | Issue 01 | Pages 29-36

Journal homepage: https://fupubco.com/futech

https://doi.org/10.55670/fpll.futech.4.1.4

Future Publishing LLC

Article

# Experimental investigation of a cooling and cleaning system for enhanced photovoltaic panel performance

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**ARTICLE INFO**

*Article history:*
Received 07 December 2024
Received in revised form
11 January 2025
Accepted 22 January 2025

Keywords:
Photovoltaic panels, Cooling system, Cleaning, Control, Efficiency

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DOI: 10.55670/fpll.futech.4.1.4

**ABSTRACT**

This paper presents the design and development of a cooling and cleaning system for photovoltaic (PV) installations. The key contribution of this work is the use of an Arduino-controlled closed-loop water circulation system to clean and cool the PV panels. The proposed solution incorporates sensors to measure the temperature, current, and voltage of the PV panels, as well as the water level in the tank. These measurements are used to control the pump's operation, regulating the flow of water across the PV panels. The study aims to improve the performance of PV systems by addressing two main challenges: the heating of the panels and the accumulation of dust. In regions like the Sahara, dust and sand reduce the efficiency of PV panels, necessitating regular cleaning. To address these issues, a cooling and cleaning prototype was developed. Tests and temperature measurements were performed under identical weather conditions (i.e., the same ambient temperature and solar radiation), demonstrating the effective operation of the proposed system and an improvement in PV efficiency. The automated cooling and cleaning system successfully reduced the panel temperature and boosted the output power to 287.81 W under radiation of 761.13 W/m², resulting in an efficiency of 19.15%. In contrast, under the same radiation, the uncooled panels produced only 283.48 W, yielding an efficiency of 18.86%, a 4.33 W difference.

## 1. Introduction

Today, the world is facing an acute energy crisis, which has sometimes been a source of conflict between nations. As a result, countries worldwide are increasingly focused on promoting renewable energy sources, with solar PV technology emerging as a key solution to the problem of electricity production. PV energy is generated by directly converting a portion of solar radiation into electrical energy. This conversion occurs through PV cells, which are made from semiconductors and rely on a physical phenomenon known as the PV effect the generation of an electromotive force when the cell's surface is exposed to light. Solar PV energy aligns well with global ecological policies aimed at meeting the growing demand for energy while reducing environmental impact. PV systems can be categorized into grid connected and autonomous systems. In autonomous systems, the integration of energy storage is essential to address the intermittency of the energy source and fluctuations in energy consumption. In recent years, photovoltaic energy has been applied to a variety of sectors, including electric vehicles (EVs) and robotics. To maximize the efficiency of energy transfer from the PV system to the load, a maximum power point tracking (MPPT) algorithm is commonly used. Despite advancements, the efficiency of silicon based PV cells remains below 20%, while multi junction solar cells can achieve efficiencies of up to 40%. However, a significant portion of the absorbed energy around 80% for silicon cells and 60% for multi junction cells is converted into heat, which increases the temperature of the PV cells. This temperature rise can lead to hot spots, potentially causing damage and a considerable decrease in electrical efficiency. Moreover, it can contribute to the degradation of PV panels, increased electrical resistance, and voltage drops in wiring and connectors. In addition to temperature-related issues, dust and sand accumulation on PV panels further reduces their efficiency. To address these challenges, scientists worldwide are actively researching solutions for the cleaning and cooling of PV panels. A significant body of research has been published on PV cooling. Studies presented in Refs. [1-4] highlight the benefits of air-based cooling systems for PV panels.

**Abbreviations**

| | |
|---|---|
| PVG | Photovoltaic generator |
| PCM | Phase change material |
| STC | Standards Tests Conditions |
| HMT | Total head |
| MPPT | Maximum power point tracking |

**Nomenclature**

| | |
|---|---|
| $Ha$ | Geometric suction height |
| $Hr$ | Geometric discharge height |
| $Jc$ | Load losses in the elbows |
| $Ja$ | Pressure losses in the suction and discharge piping |
| $Pu$ | Desired useful pressure |
| $D$ | Diameter |
| $H$ | Height |
| $E$ | Solar radiation |
| $T$ | Temperature |
| $U$ | Voltage |
| $I$ | Current |
| $P$ | Power |

These works explore how wind speed influences the performance of PV panels, showing that air circulation reduces the effects of high temperatures and improves electrical efficiency. Ref. [5] focuses on liquid-based cooling systems for PV panels, discussing various methods to enhance solar cell performance, particularly through jet impact cooling technology in hybrid systems. This approach uses natural coolant circulation to extract heat from the panels. In addition, Ref. [6] investigates the effect of forced water circulation for cooling. This study examines the impact of dual-surface simultaneous cooling on the output performance of PV modules, resulting in an average efficiency improvement of 1.53%. The authors' approach significantly enhances the energy efficiency of the PV system. Other studies, such as those in Refs. [7-13], explore passive cooling methods, including cooling by phase change materials, heat pipes, heat exchangers, micro channel heat exchangers, radiative sky cooling, nano-fluid-based cooling, thermoelectric cooling, evaporative cooling, and spectral filter cooling. Furthermore, Refs. [14-20] discuss ongoing research on hybrid and multi-concept cooling systems currently under development.

The research presented in this paper aims to contribute to improving the efficiency of PV panels through a cooling and cleaning system powered by an Arduino controller. To increase the electrical power generated by two PV panels, the system uses sensors to acquire key data: the temperature, current, and voltage of the panels, as well as the water level in the tank. Based on these measurements, a pump control system ensures the circulation of water, which cools the panels and removes dust and sand that accumulate on their surface. The objective of our experimental work is to validate the proposed solution by demonstrating the increase in efficiency of the two PV panels. To achieve this, we conduct a comparative study of the energy production of the two panels before and after implementing the automated cooling and cleaning system. The results show a noticeable increase in power production, confirming that water-cooled PV panels improve electrical output and enhance efficiency.

This paper is organized into six sections. Section 1 introduces the research on cooling and cleaning systems for photovoltaic panels. Section 2 provides a detailed description of the cooling system developed for two photovoltaic panels. Section 3 addresses the design and sizing of the cooling and cleaning system. Section 4 discusses the control strategy implemented for the system. Section 5 presents experimental results to validate the proposed solution. Finally, Section 6 concludes the paper.

## 2. Description of the system

PV systems are an excellent means of producing electrical energy, but they face operational challenges. High temperatures can reduce the efficiency and lifespan of PV panels, as well as increase the risk of fire and damage. For this reason, cooling PV systems are not only beneficial for the environment, but they also enhance energy production and improve the efficiency of the panels. Water cooling systems are the most commonly used in PV installations because they offer many advantages. Water's thermal properties make it one of the best heat transfer fluids. In addition to its availability, water has a very high specific heat capacity (4180 J/kg°C), allowing it to absorb a large amount of heat. For these reasons, we chose water as the cooling fluid. The goals of integrating a water-based cooling system include:

- Increasing the electrical power output of the PV panels by reducing their temperature.
- Cleaning the panels to assess the impact of dust deposits on their performance. This study focuses on the southern regions of Tunisia, where the presence of the Sahara results in significant amounts of sand and dust. These deposits reduce the efficiency of the panels by covering them.

To achieve this, we use a system of running water above the panels for cooling. The system consists of the following components:

- Two PV panels with identical characteristics, mounted in series on an aluminum structure.
- A closed-loop water circulation system, consisting of a pipe with holes of equal diameter. One end of the pipe is closed, while the other is connected to a pump.
- Water from the pipe flows over the entire surface of the panels and is collected in a separate water pipe.

Figure 1 illustrates the two sides of the prototype cooling system for the two PV panels. The water collected in the pipe is directed to a storage tank through a pump, after passing through a filtering stage to remove impurities. To ensure the continuous circulation of water in a closed loop, minimize water loss, and use a limited amount of fluid, a 0.5 HP pump is employed. This pump circulates the water from the storage tank to the perforated pipe and draws water back into the cistern from the collection pipe.

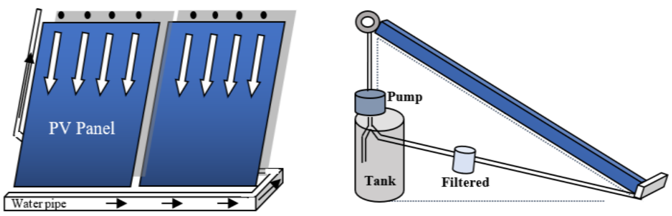


**Figure 1.** Front and left views of the prototype cooling system for two PV panels

## 3. Photovoltaic panel cooling system

### 3.1 Sizing of the PV cooling system

PV panel structures are passive components designed to facilitate installation. They must be able to withstand all external weather conditions. The structure is fixed at an inclination of 30°, which allows the solar modules to receive optimal solar radiation. It is mounted on four concrete supports, each with a height of 150 mm, as shown in Figure 2.

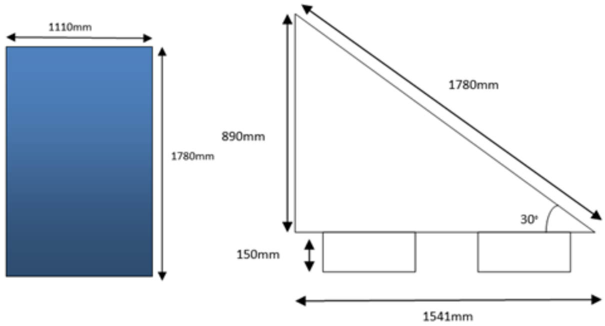


**Figure 2.** Sizing of the PV Panel Structure

The proposed cooling and cleaning system utilizes a multi-layer pipe placed above two PV panels, capped on the right side to ensure closed circulation of water. The pipe has the following specifications: a length of 2230 mm, a diameter of 20 mm, and holes of 4 mm in diameter, as shown in Figure 3. The water pipe, made of PVC, is positioned below the panels to collect the water that flows over the entire surface. It is inclined at an angle of 2.3° to facilitate the easy suction of water by the pump.

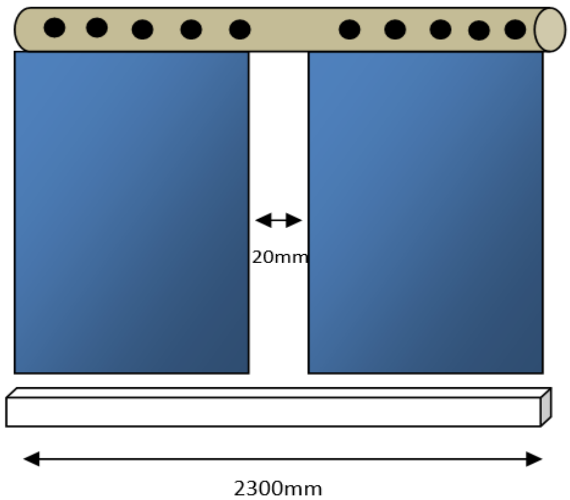


**Figure 3.** Pipe and water line sizing

The mounting platform of this tank is designed to accommodate a dosing pump and an electro-stirrer at the front. Two level sensors will be installed on the tank to monitor the minimum and maximum water levels (Figure 4). To calculate the volume of water required to fill the cistern, the following formula can be used, based on the diameter of the basin:

$$V = \frac{\pi D^2 H}{4} \qquad (1)$$

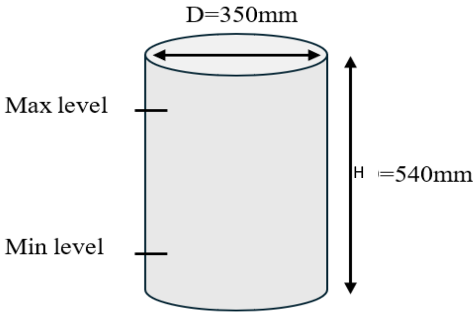


**Figure 4.** Trank sizing

The transition from the suction stage to the water discharge stage is facilitated by a pump, which operates based on the total head (HTM). This head is calculated using the following equation:

$$HMT=Ha+Hr+Ja+Jc+Pu \qquad (2)$$

"Ha" represents the suction height, "Hr" represents the discharge height, and "Ja+Jc" represents the average pressure losses in the pipes (which depend on the flow rate, pipe length and diameter, as well as any elbows, valves, taps, etc.). "Pu" represents the discharge pressure at the pump outlet (Figure 5).

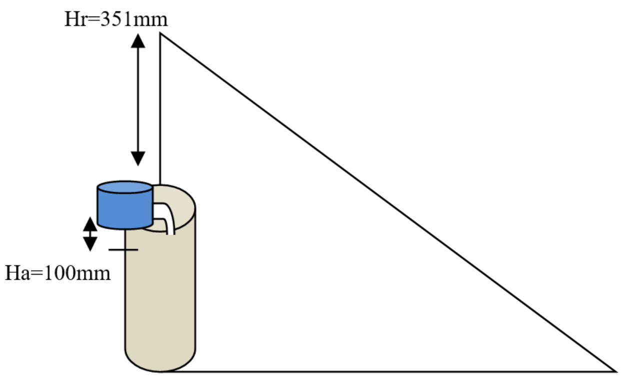


**Figure 5.** Pump sizing

### 3.2 Design of the control system for the PV cooling system

The cooling and cleaning system for the two PV panels is controlled by an "Arduino" board. A temperature sensor and two level sensors are integrated into the system to automatically control the pump's operation. When the temperature reaches 40°C, the pump is triggered to start automatically. Additionally, when the water level in the storage tank decreases, a level sensor sends a signal to the "Arduino" board. A control algorithm then activates the pump to refill the tank. Once the second level sensor detects the maximum water level, it deactivates the pump. Figure 6 shows the placement of the temperature sensor and the pump's operational conditions.

## 4. Implementation of the proposed cooling and cleaning method for PV panels

In this section, we present the method for cooling and cleaning the two PV panels. Several factors must be considered, including the size of the panels and the local climate and weather conditions. To enhance the output and efficiency of the PV system, we propose a control algorithm that regulates the operation of the pump. This ensures the system remains adequately cooled while maintaining an appropriate water level in the tank. Figure 7 illustrates the pump control flowchart, which manages both the cooling of the PV panels and the water level in the tank.

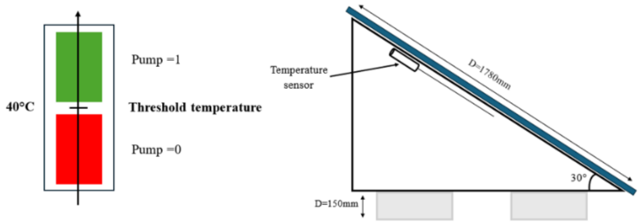


**Figure 6.** Operating conditions of the pump based on the temperature measurements of the two PV panels

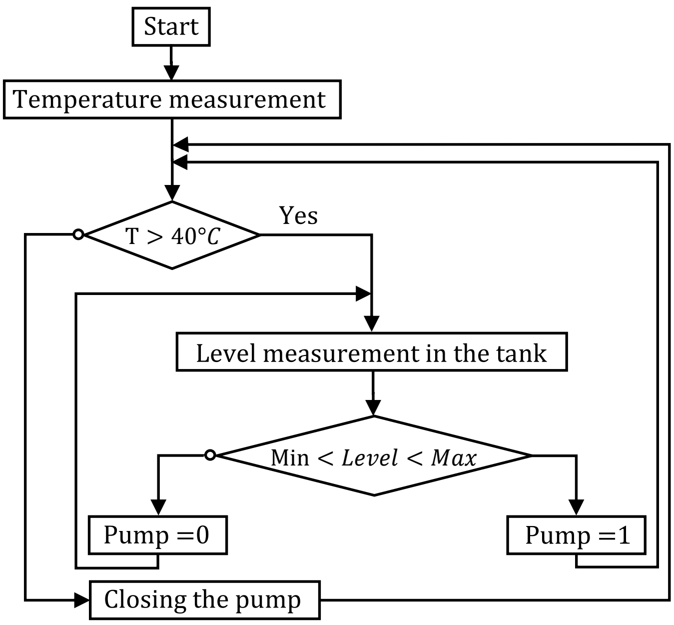


**Figure 7.** Pump control flowchart for PV panel cooling and cleaning system

The algorithm requires input data from a temperature sensor and two water level sensors in the tank. If the temperature of the panels exceeds 40°C, the "Arduino" board generates a control signal to activate the pump. The water level in the tank is monitored by "Min" and "Max" sensors to ensure there is always sufficient water in the cooling system.

## 5. Experimentation of the proposed cooling and cleaning method for PV panels

The experimental implementation of the proposed cooling system is carried out using an "Arduino" board. The board receives input from various measured quantities, which are processed in real-time according to the control algorithm we have developed. Figure 8 illustrates the progress of this project, showing the activation process for the cooling and cleaning system of the two PV panels. In this section, we present the results of the tests conducted. As mentioned earlier, the two panels were exposed to identical radiation and temperature conditions. A voltmeter and an ammeter were used to measure the voltage and current of the panels, both before and after cooling, to assess the impact of temperature on electrical power.

The experimental data in Table 1 were collected on a sunny day in October (October 12, 2024), from 11:35 a.m. to 1:30 p.m.

Figure 9 shows the evolution of the surface temperature of the two PV panels over the time interval from 11:35 a.m. to 1:30 p.m., both with and without the cooling system. The use of water for cooling leads to a significant reduction in the surface temperature of the panels. A temperature difference of more than 19°C is observed between the panels with and without cooling.

For the panels without cooling, the temperature ranges from 41°C to 54.5°C between 12:00 p.m. and 1:00 p.m., while for the panels with cooling, the temperature remains between 32°C and 36.5°C. This clearly demonstrates that the cooling system helps maintain lower temperatures, improving the panels' performance. Figure 10 illustrates the power output of the two PV panels, both with and without the proposed cooling system. The figure shows a noticeable difference in performance between the two panels. For the cooled panels, the power output is 287.81 W at a radiation level of 761.13 W/m$^2$, while for the same radiation, the uncooled panels produce only 283.48 W, resulting in a difference of 4.33 W.

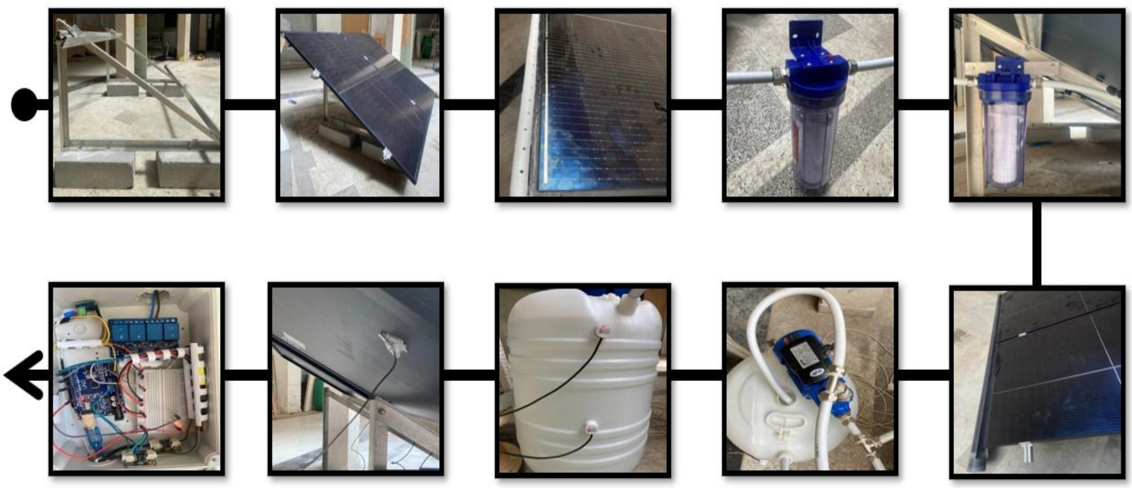

**Figure 8.** Hardware and software description of the cooling and cleaning system for two PV panels

**Table 1.** Experimental results of the two PV panels: with and without the cooling and cleaning system

| | | Before cooling and cleaning system | | | | After cooling and cleaning system | | | |
|---|---|---|---|---|---|---|---|---|---|
| Time | E (W/m²) | T (°C) | U (V) | I (A) | P (W) | T (°C) | U (V) | I (A) | P (W) |
| 11.35 | 761.13 | 33 | 75.3 | 3.59 | 270.327 | 30.06 | 75.2 | 3.59 | 269.968 |
| 11.45 | 761.13 | 35.1 | 75.3 | 3.88 | 292.164 | 29.6 | 75.25 | 3.88 | 291.97 |
| 11.50 | 761.13 | 37.3 | 74.6 | 3.8 | 283.48 | 30.05 | 75.74 | 3.8 | 287.812 |
| 12.00 | 779.30 | 41 | 74.36 | 4 | 297.44 | 32 | 75.04 | 4 | 300.16 |
| 12.05 | 779.30 | 42 | 74.28 | 4.4 | 326.832 | 33.4 | 75 | 4.4 | 330 |
| 12.10 | 779.30 | 44.1 | 74.22 | 4.4 | 326.568 | 33.8 | 74.82 | 4.4 | 329.208 |
| 12.15 | 779.30 | 45.2 | 74 | 4.7 | 347.8 | 34 | 74.84 | 4.7 | 351.748 |
| 12.20 | 779.30 | 49.9 | 73.96 | 4.7 | 347.612 | 34.8 | 74.8 | 4.74 | 354.552 |
| 12.25 | 779.30 | 52.9 | 73.68 | 4.8 | 353.664 | 35.2 | 74.78 | 4.79 | 358.1962 |
| 12.30 | 739.08 | 54.5 | 73.72 | 4.8 | 353.856 | 35.7 | 74.5 | 4.8 | 357.6 |
| 12.35 | 739.08 | 51.6 | 73.6 | 4.8 | 353.28 | 35.7 | 74.66 | 4.8 | 358.368 |
| 12.40 | 739.08 | 49.7 | 73.5 | 4.7 | 345.45 | 36 | 74.56 | 4.72 | 351.9232 |
| 12.45 | 739.08 | 45.5 | 73.4 | 3.3 | 242.22 | 36.5 | 74.3 | 3.32 | 246.676 |
| 12.50 | 739.08 | 44 | 72.98 | 3.09 | 225.5082 | 36.2 | 74 | 3.2 | 236.8 |
| 13.00 | 698.86 | 39.5 | 72.8 | 1.94 | 141.232 | 33.7 | 73.4 | 1.95 | 143.13 |
| 13.10 | 698.86 | 38.2 | 70.84 | 1.69 | 119.7196 | 30.4 | 71.98 | 1.69 | 121.6462 |
| 13.15 | 698.86 | 35.4 | 69.64 | 0.99 | 68.9436 | 28.7 | 70 | 0.95 | 66.5 |
| 13.20 | 698.86 | 32.1 | 69.04 | 0.89 | 61.4456 | 29 | 69.74 | 0.9 | 62.766 |
| 13.30 | 654.63 | 31 | 68.1 | 0.76 | 51.756 | 28.1 | 68.62 | 0.76 | 52.1512 |

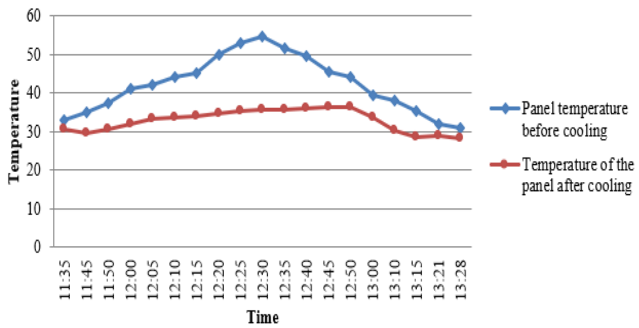


**Figure 9.** Surface temperature of the two PV panels: with and without cooling

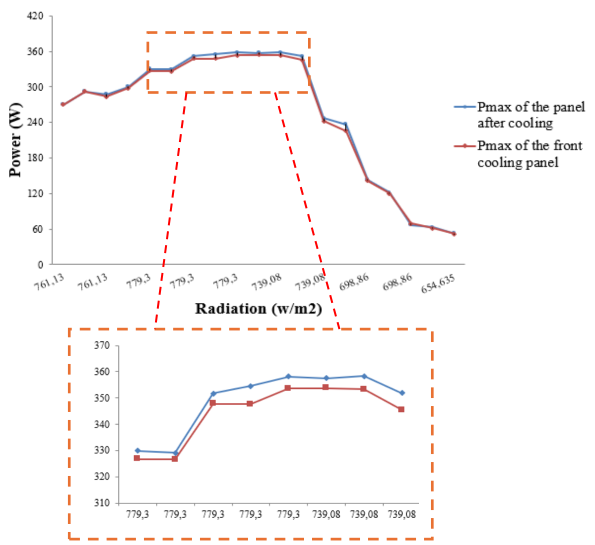


**Figure 10.** PV production of two panels: with and without cooling system

Figure 11 and Figure 12 present, respectively, the voltage and current generated by the two PV panels at various illuminance levels during the time interval from 11:35 a.m. to 1:30 p.m., both with and without the use of the cooling system. The rise in temperature activates the cooling system, which leads to an increase in voltage, demonstrating an improvement in the efficiency of the PV panels.

The efficiency of the two PV panels, both before and after the insertion of the cooling system, is shown in Table 2. The experimental results indicate an improvement in performance across five different irradiance levels. The power output increases when the cooling system is activated. Figure 13 presents the results from Table 2 in graphical form. PV systems are exposed to a wide range of environmental factors that can significantly reduce their energy production efficiency, especially when the panel surfaces become dirty (e.g., due to dust, sand, etc.). The proposed cooling system also ensures automatic cleaning of both PV surfaces.

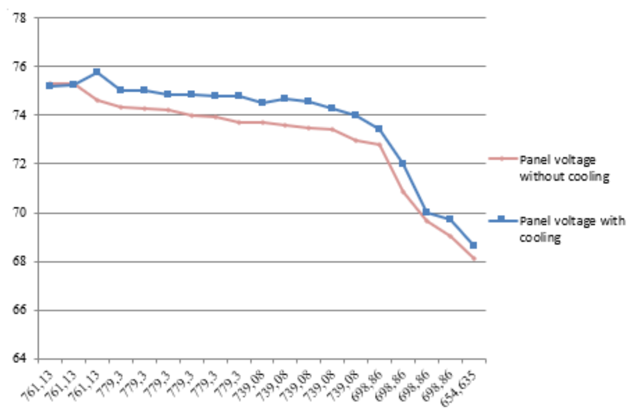


**Figure 11.** Voltage of the two PV panels

Figure 14 illustrates the initial and final states of the two PV surfaces, as well as the impact of cleaning on the water filter cartridge during the water recovery phase in the tank. Figure 15 presents an explanatory diagram showing the connections between the Pt100 temperature probe, the two level sensors, and the "Arduino" board, which are used to control the activation and deactivation of the pump.

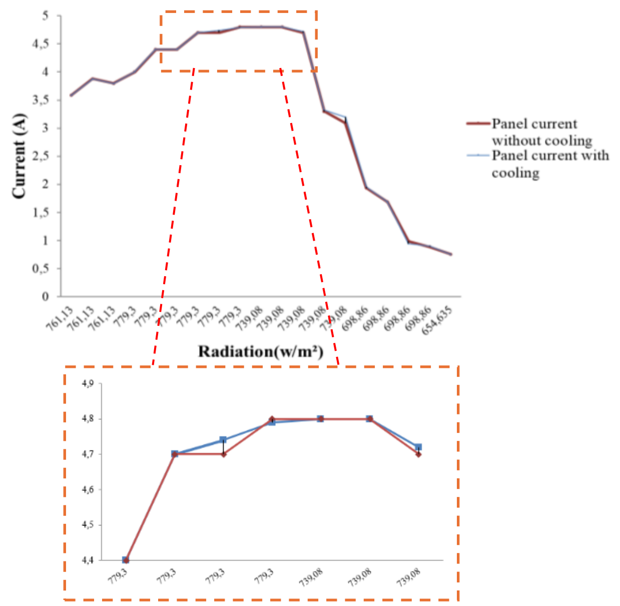


**Figure 12.** Current of two PV panels

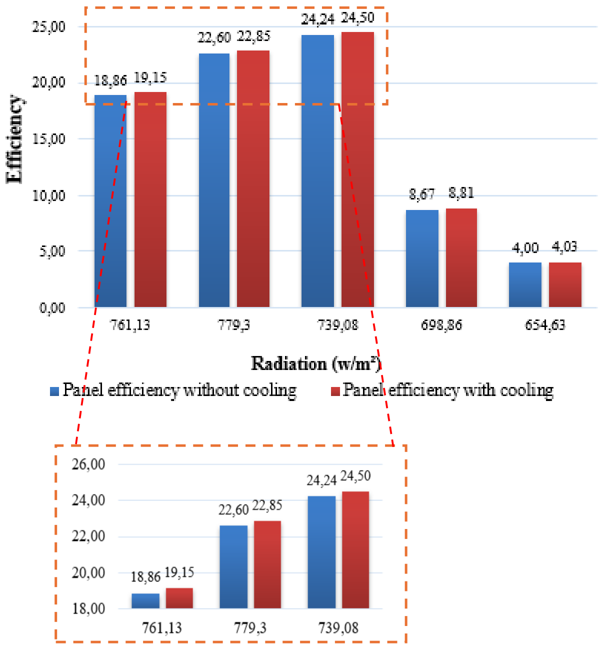


**Figure 13.** Yield of the two PV panels with and without cooling and cleaning system implementation

**Table 2.** Yield comparison of the two PV panels before and after cooling and cleaning system implementation

| | Before cooling and cleaning system | | After cooling and cleaning system | |
|---|---|---|---|---|
| E (W/m$^2$) | Power (W) | Efficiency | Power (W) | Efficiency |
| 761.13 | 283.48 | 18.86 | 287.81 | 19.15 |
| 779.30 | 347.8 | 22.6 | 351.74 | 22.85 |
| 739.08 | 353.856 | 24.24 | 357.6 | 24.5 |
| 698.86 | 119.7196 | 8.67 | 121.64 | 8.81 |
| 654.63 | 51.756 | 4.00 | 52.15 | 4.03 |

**Figure 14.** Influence of the cleaning system on both PV panels and the water filter: (a) Before water runoff; (b) After water runoff

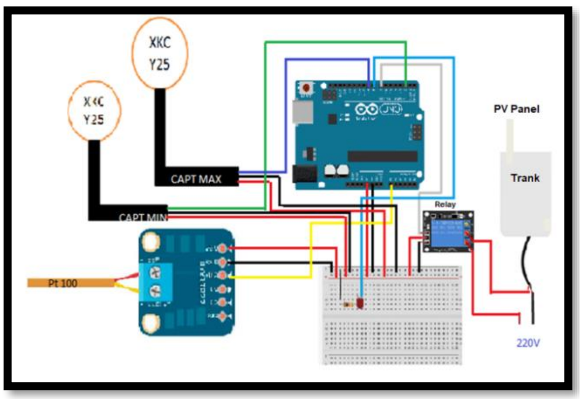


**Figure 15.** Explanatory diagram of the connection between the sensors and the "Arduino" board for pump control

## 6. Conclusion

The work presented focuses on the design and development of a cooling system for two PV panels, using a water pump controlled by an "Arduino" board. The aim is to implement a technical solution to cool and clean the panels, thereby reducing their temperature and improving their performance. Temperature measurements and tests on the panels were conducted under the same weather conditions (identical temperature and illumination). The proposed cooling system produced satisfactory results, reducing the temperature of both panels by more than 19°C and increasing their power output by approximately 5 W, which translates to improved performance. The experimental results, obtained under various conditions, demonstrate the effectiveness of the developed cooling and cleaning system.

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

**Data availability statement**
The datasets analyzed during the current study are available and can be given upon reasonable request from the corresponding author.

**Conflict of interest**
The authors declare no potential conflict of interest.

**References**
[1] M. El H. Attia, M. E. Zayed , A. E. Kabeel , A. Khelifa , K. Irshad , S. Rehman. Numerical analysis and design of a novel solar photovoltaic thermal system using finned cooling channel structures embedded with air/TiO2–water nano bi-fluid. Solar Energy. vol 269, pp. 112368. 2024. https://doi.org/10.1016/j.solener.2024.112368

[2] F. F. Ahmad, C. Ghenai, A. K. Hamid, O. Rejeb, M. Bettayeb. Performance enhancement and infra-red (IR) thermography of solar photovoltaic panel using back cooling from the waste air of building centralized air conditioning system. Case Studies in Thermal Engineering, vol. 24, pp. 100840, 2021. https://doi.org/10.1016/j.csite.2021.100840

[3] W. Salameh, J. Faraj, M. Khaled. Numerical study of cooling photovoltaic panels with air exhausted from industrial systems: Comparisons and innovative configurations. International journal of thermo fluids, vol. 20, pp. 100493, 2023. https://doi.org/10.1016/j.ijft.2023.100493

[4] M. Patil, A. Sidramappa, S. K. Shetty, A. M. Hebbale. Experimental study of solar PV/T panel to increase the energy conversion efficiency by air cooling. Materialstody: Proceedings, vol. 92, pp. 309-313, 2023. https://doi.org/10.1016/j.matpr.2023.05.007

[5] S. S. C. Ghadikolaei. Solar photovoltaic cells performance improvement by cooling technology: An overall review. International Journal of Hydrogen Energy, vol. 46, pp. 10939-10972, 2021. https://doi.org/10.1016/j.ijhydene.2020.12.164

[6] E. B. Agyekum, S. P. Kumar, N. T. Alwan, V. I. Velkin, S. E. Shcheklein. Effect of dual surface cooling of solar photovoltaic panel on the efficiency the module: experimental investigation. Heliyon, vol. 7, e07920, 2021. https://doi.org/10.1016/j.heliyon.2021.e07920

[7] M. A. Alazwari , A. Basem , H. A. Z. AL-bonsrulah , N. H. Abu-Hamdeh , M. S. Albdeiri , G. A. A. Alashaari. Simulation of behavior of solar panel in existence of nanomaterial as cooling system. Case Studies in Thermal Engineering. vol 63, pp. 105306. 2024. https://doi.org/10.1016/j.csite.2024.105306

[8] Y. Sheikh, M. Jasim, M. O. Hamdan , B. A. Abu-Nabah, F. Gerner. Design and performance assessment of a solar photovoltaic panel integrated with heat pipes and bio-based phase change material: A hybrid passive cooling strategy. Journal of Energy Storage. vol 100, pp, 113706. 2024. https://doi.org/10.1016/j.est.2024.113706

[9] M. A. Alnakeeb, M. A. Abdel Salam, M. A. Hassab, W. M. El-Maghlany. Numerical study of thermal and electrical performance of a new configuration of hybrid photovoltaic solar panel phase-change material cooling system. Journal of Energy Storage. vol 97, pp, 112945, 2024. https://doi.org/10.1016/j.est.2024.112945

[10] N. S. Altawi, A. M. Almutairi, S. A. Khalil, A. O. Alatawi, W. Al-Anazi, M. Magherbi. Qualitative modeling of solar panel cooling by nanofluid jets: Heat transfer and second law analysis. Case Studies in Thermal Engineering, vol. 45, pp. 102981, 2023. https://doi.org/10.1016/j.csite.2023.102981

[11] T. Hai, O. I. Awad, S. Li, J. M. Zain, A. A. H. Karah Bash. The impact of using a turbulator at the nanofluid flow inlet to cool a solar panel in the presence of phase change materials using artificial intelligence. Engineering Analysis with Boundary Elements, vol. 152, pp. 301-310, 2023. https://doi.org/10.1016/j.enganabound.2023.03.025

[12] R. I. Hatamleh, M. J. H. Rawa, N. H. Abu-Hamdeh, B. Shboul, A. Karimipour. Simulation of nanofluid flow in a solar panel cooling system to investigate the panel's electrical-thermal efficiency with artificial neural network. Journal of the Taiwan Institute of Chemical Engineers, vol. 148, pp. 104879, 2023. https://doi.org/10.1016/j.jtice.2023.104879

[13] S. Bhattacharyya, N. Jain, T. Bhatt, H. Yasmin, M. Sharifpur. Mini-channel cooling system for solar PV Panels with hybrid magnetic nanofluid and magnetic field. Results in Engineering, vol. 20, pp. 101473, 2023. https://doi.org/10.1016/j.rineng.2023.101473

[14] M. Chandrasekar. Chapter 29 - Hybrid cooling systems for enhancing the electrical performance of solar photovoltaic (PV) panels. Handbook of Thermal Management Systems, pp. 639-657, 2023. https://doi.org/10.1016/B978-0-443-19017-9.00020-9

[15] G. Yildiz, M. O. Karaagac, A. Ergun, M. Kayfeci. Chapter 28 - Solar panel cooling using hybrid cooling systems. Handbook of Thermal Management Systems, pp. 623-638, 2023. https://doi.org/10.1016/B978-0-443-19017-9.00005-2

[16] L. Chanphavong, V. Chanthaboune, S. Phommachanh, X. Vilaida, P. Bounyanite. Enhancement of performance and exergy analysis of a water-cooling solar photovoltaic panel. Total Environment Research Themes, vol. 3-4, pp. 100018, 2022. https://doi.org/10.1016/j.totert.2022.100018

[17] D. Govindasamy, A. Kumar. Evaluation of the impact of different composite phase change materials on reduction in temperature and enhancement of solar panel efficiency. Journal of Energy Storage, vol. 60, pp. 106631, 2023. https://doi.org/10.1016/j.est.2023.106631

[18] M. S. Sheik, P. Kakati, D. Dandotiya, U. Ravi M, Ramesh C S. A comprehensive review on various cooling techniques to decrease an operating temperature of solar photovoltaic panels. Energy Nexus, vol. 8, pp. 100161, 2022. https://doi.org/10.1016/j.nexus.2022.100161
[19] K. Bilen, I. Erdogan. Effects of cooling on performance of photovoltaic/thermal (PV/T) solar panels: A comprehensive review. Solar Energy, vol. 262, pp. 111829, 2023. https://doi.org/10.1016/j.solener.2023.111829
[20] D. L. Pascual, I. V. Blanco. O. M. Narro, M. F. Munoz, E. D. Jimenez. Experimental characterization of a geothermal cooling system for enhancement of the efficiency of solar photovoltaic panels. Energy Reports, vol. 8, pp. 756-763, 2022. https://doi.org/10.1016/j.egyr.2022.10.154