Enhancing the Efficiency of Solar Panels by Utilizing the Water Cooling System: the Case of Study the City of Tobruk

Authors

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ABSTRACT

Solar panels are a clean and reliable source of renewable energy, but their efficiency drops significantly as their temperature rises—especially in hot, sunny regions like Libya. In such climates, panel temperatures can exceed 65°C, reducing electrical output by up to 20% compared to standard test conditions. To address this challenge, this study evaluates asimple, low-cost water-cooling system designed to improve the performance of a 150 W monocrystalline photovoltaic (PV) panel. The cooling system uses intermittent water spraying: water is sprayed for 1 minute, then stopped for 12 minutes, creating an energy-efficient cycle. Experiments were conducted in Tobruk (August–September-October 2025), comparing a cooled panel with an identical uncooled reference panel under identical environmental conditions. Results showed that the water-cooling system reduced the panel's average operating temperature by 14°C, from 53°C to 39°C. This led to a noticeable increase in electrical output, raising the average power from 130 W (uncooled) to 155 W (cooled)—a 17.3% improvement. After accounting for the cooling system's average power consumption (5.5 W), the net energy gain was 15.85 W (≈10.5 % net increase). Water usage was minimized to 0.6 liters per hour, making the system suitable even in water-scarce areas. In conclusion, this study demonstrates that even a simple water-cooling method can significantly enhance PV performance in hot climates. When designed with low energy and water consumption, such systems offer a practical and cost-effective solution for improving solar energy yield—especially for small- to medium-scale installations.

Keywords: Solar panel cooling, Water cooling, PV efficiency, Intermittent spraying, Net energy gain; Tobruk

1. INTRODUCTION

Utilizing naturally occurring energy flows that are found in the environment is known as renewable energy [1]. Demanding energy has a big impact, especially on renewable energy because less developed nations are becoming more and more dependent on electricity [2], and They are now the energy of the future thanks to solar technologies. These technologies fall into two categories: passive (like using solar energy to heat water) and active (like solar panels) [3]. Photovoltaic systems use light absorption to generate electricity, in contrast to solar thermal systems that use light energy to provide heat. Three steps make up photovoltaic (PV) operation: light absorption, charge carrier separation, and separate carrier extraction. Hole-electron pairs are produced in the first step [4]. Because it's crucial to maximize light absorption and reduce reflecting energy, absorber thickness plays a significant role in solar cell design [5]. Numerous technologies, like nanoscale, increase the solar cell's efficiency by absorbing more light [6]. The demand for energy is rising significantly on a global scale. The sustainable growth of civilization depends on a clean and safe energy supply. Growing quickly, solar and wind energy can make a substantial contribution to achieving the targets set by numerous nations to lower greenhouse gas emissions [7]. Solar photovoltaic (PV) systems have the potential to generate electricity with minimal emissions during operation, enabling electricity consumers to meet at least a portion of their demand [8]. In 2020, the world's PV capacity rose to about 760 GW, an increase of roughly 139 GW from 2019 [9]. When only Europe is taken into account, Poland's PV market is expanding at the second-fastest rate in Europe, after Germany. Every year, PV installations' capacity grows dramatically, changing the energy mix and lowering the proportion of fossil fuels used in the production of electricity [10]. The installed photovoltaic capacity reached 8.77 GW in February 2022 [11]. PV panels are typically installed on building roofs or structurally integrated into structures by taking the place of the conventional building envelope [12], [13]. Building integrated photovoltaics (BIPV) are more expensive than conventional units. For instance, a thin-film BIPV façade with basic substructures and low-efficiency PV technology costs between 100 and 150 €/m2, while a high-efficiency BIPV crystalline module costs between 500 and 700 €/m2. Conversely, depending on the materials used, the cost of traditional roofing and façades can range from 80 to 900 €/m^2 [14]. Eighty percent of Poland's installed PV power comes from such small-scale systems. PV panels are being utilized more and more not only in construction but also in the electromobility industry to power vehicles such as cars, airplanes, and boats [15], [16].

Authors in [17] created a test of Libya's artificial river hydroelectricity model (LMR HEM), authors in [18] created and examined a small HAWT experimental design for home electricity in the lab at the Libyan Academy for Postgraduate Studies in AlBayda, Libya. In their paper, they evaluated the wind energy data in Al-Bayda, East of Libya, using experimental work., authors in [19] The experimental work for their project, which is based on an energy analysis of a solar air heating collector, uses recycled aluminum cans as the absorbing material., authors in [20] created and produced a centrifugal water pump in order to investigate the impact of the number of impeller blades on the pump's performance. The flow rate, velocity, head, and power of the pump were examined and measured experimentally, authors in [21] created a model of a solar water pump to investigate how the number of impeller blades affects the pump's performance.

Authors in [22] focused on using water spraying on the solar cell façade to enhance the performance of the PV water pumping system. According to their findings, water spraying successfully lowers cell temperature and enhances optical performance, increasing system efficiency and pump flow rate under various operating heads.. Similarly, authors in [23] carried out an experimental investigation on front-surface water cooling and found a notable increase in exergetic and electrical conversion efficiency. Authors in [24] examined how various cooling systems affected the efficiency of PV panels in hot conditions by contrasting air cooling, water cooling, and a hybrid setup that combined both techniques. According to their findings, the hybrid system improved overall by 2% and increased electrical capacity by more than 13% by lowering the temperature of the panels by up to 40%. Authors in [25] showed the impact of employing aluminum foil reflectors and water cooling techniques, reporting a decrease in panel temperature from 61.3 °C to 29.5 °C and an increase in efficiency to 10.36% as opposed to 5.52% in the absence of either technology. These findings imply that the performance of solar panels can be greatly increased by combining water cooling with inverters. Authors in [26] assessed the performance of photothermal collector employing a coolant and nanofluid. According to their findings, compared to traditional water cooling, a nanofluid containing 0.1% manganese oxide (MnO) improved electrical efficiency. Authors in [27] examined how a mist spray cooling system affected the performance of solar PV panels on the Graduate Studies Department roof, showing a significant increase in panel efficiency as a result of efficient temperature reduction. Authors in [28] examined how a direct water cooling system affected solar PV panel performance in both lab and real-world settings. In comparison to uncooled panels, their results demonstrated efficiency gains of up to 12%, while actual conditions showed increases in energy production of 1.2% and 13.0%, with an average weekly improvement of 10.3%. Authors in [29] created a hybrid system that uses water cooling to increase the efficiency of solar PV panels. In addition to producing usable hot water (19.93 °C and 54.86 °C) that can help lower fuel consumption and operating costs, experiments revealed an efficiency increase from 15.74% to 17.1% at a flow rate of 10 L/min. Authors in [30] found a 6.2% increase in electrical and thermal efficiency when comparing naturally loaded water-cooled solar panels with modular panels. Authors in [31] examined active cooling technologies to increase solar panel efficiency. The study offers a thorough analysis of the literature on various cooling systems, including air and water cooling, and contrasts how well they work to lower panel temperatures and boost electrical efficiency. Authors in [32] employed a hybrid PV cooling system that combined water spraying and evaporative cooling, resulting in temperature drops of 29.7 °C and efficiency gains of up to 20%. Authors in [33] examined porous nanochannel-based cooling devices and found surface temperature drops of 31.5 °C, which led to a 33% increase in electrical energy production and a 33% decrease in response time. Authors in [34] showed that, in hot climates, rear-surface cooling greatly increases PV efficiency through efficient temperature reduction; these results are directly consistent with the approach used in this study. Also, authors in [35] shown that the flow of water on PV panels greatly boosts electrical productivity, supporting the inverse relationship between efficiency and temperature and offering a theoretical foundation for the idea of water cooling. Authors in [36] created an active pumped water cooling system that supported the use of pumps in the suggested system by greatly enhancing thermal and electrical performance. Authors in [37] provided a thorough analysis that demonstrated a 9% increase in efficiency with a 20 °C temperature drop, offering a crucial quantitative benchmark for comparing the outcomes. Authors in [38] carried out a thorough critical analysis of PV cooling technologies, offering a theoretical framework for comprehending cooling mechanisms and supporting the selection of water cooling as a practical substitute for complicated systems. Furthermore, authors in [39] The decision to use a closed water cycle system was supported by the application of hydrospray technology, which showed an improvement in thermal and electrical response along with a thorough economic feasibility analysis. Similarly, authors in [40] verified by a pilot study that water cooling greatly enhances PV panel performance, strengthening the validity of the methodology employed in this study.

2. MATERIAL

2.1 Monocrystalline solar panel

LUMINOUS Luminous Power Technologies Pvt.Ltd.
ADD: Plot No. 150, Sector – 44, Gurgaon – 122003,Haryana, India

Model No.	LUM150M
Serial No.	812200810244
Production date	2020-08-15
Peak power/Pmax(W)	150
Power tolerance range(W)	0-5
Open circuit voltage/Voc(V)	22.55
Rated voltage/Vmp(V)	18.5
Short circuit current/Isc(A)	8.52
Rated current/Imp(A)	8.11
Max.system voltage(V)	1000
Dimension(mm)	1480*665*30
Weight(KG)	10.6
Series Fuse Rating(A)	15
Application class	Class A

Above Specification in standard test conditions (STC):1000W/m², Cell temperature 25℃,AM1.5

Warning

Solar modules generate electricity as soon as they are exposed to light,one module on its own is be low the safety extra low voltage level,but multiple modules connected in series(summing the voltage)represent a danger

Figure 1. Solar panel used in the experiment is of the monocrystalline type.

Standard 150W monocrystalline solar panel a common and reliable choice for solar setups. These panels are made from high-purity silicon cells and usually deliver an efficiency of around 18% or more. They're built to last, with a tough tempered glass front, a corrosion-resistant aluminum frame, and a weatherproof junction box, making them well-suited for outdoor testing.But like all solar panels, they have one big weakness: heat. When sunlight hits the panel, not all of it turns into electricity much of it becomes heat. And as the panel gets hotter, its performance drops. In fact, for every 1°C above 25°C (the standard test temperature), the panel can lose 0.4% to 0.5% of its efficiency. Over time, this heat doesn't just lower daily output it can also wear the panel down faster.The table below summarizes the general specifications for the type of panel shown in the introduction, based on data from various manufacturers. You may find slight variations in some numbers depending on the manufacturer.

2.2 Solar MPPT Meter

Figure 2. UT673PV Solar MPPT Meter

The UNI-T UT673PV MPPT Solar Meter is a specialized portable diagnostic tool designed to test the performance and condition of solar panels. It provides key measurements to help you verify that your panel is operating efficiently and effectively .

Table 1. The following table provides a quick overview of its key functions and specifications:

Feature	Specification	Key Details
Max Power Measurement	5–800W	Primary performance indicator
Peak Power Voltage (Vmp)	12–60V	Voltage at maximum power output
Peak Power Current (Imp)	0–35A	Current at maximum power output
Open Circuit Voltage (Voc)	12–60V	Panel voltage with no load
Short Circuit Current (Isc)	0–35A	Panel current with no resistance
Power Source	Solar panel	No batteries required
Display	Large color LCD (52 × 66mm)	Shows all measurements at once
Connectors	Integrated MC4	Industry-standard, plug-and-play

4.2.1 Practical Features and Benefits

Besides basic measurements, the UT673PV includes several features that make it particularly useful for your solar projects:

Comprehensive Display: The large screen displays all five important parameters at once, eliminating the need for multiple devices or repeated tests.

1 - Field-Ready: The device is powered directly from the solar panel you're testing, so you don't have to worry about running out of battery power. Its compact and lightweight design makes it easy to carry anywhere.

2 - Built-in Protection: The device includes protection against reverse polarity, overvoltage, overcurrent, and overheating, protecting both the device and the solar panel during use.

3 - MPPT Function: It can perform manual MPPT tests, allowing for accurate analysis of the panel's maximum power point, which is critical for diagnosing performance issues.

4.2.2 Optimal Use

This device is a valuable tool for a variety of tasks:

- For solar system operation: Quickly confirm that newly installed panels are producing the expected power before the system is commissioned. For preventive maintenance: Perform periodic performance audits on existing solar systems to identify underperforming or failing panels.
- For educational and research purposes: Ideal for demonstrating solar PV performance characteristics and for experimental work, such as my research on solar panel cooling.

2.3 Infrared thermometer non-contact (CT44037)

Figure 3. Infrared thermometer

The handy, non-contact infrared thermometer. Think of it as a temperature gun that can instantly measure the surface temperature of an object from a distance without ever touching it. This makes it an incredibly useful tool for your solar panel cooling experiment.

2.4 DC Power Supply

Figure 4. DC Power Supply

A DC Power Supply is a device that provides a steady and controllable flow of Direct Current (DC) electricity. Think of it as a reliable electrical source that you can adjust to power, test, or charge your electronic projects and devices.

2.5 DC Water Pump

Figure 5. DC Water Pump

2.6 Heat sink and block made of aluminum

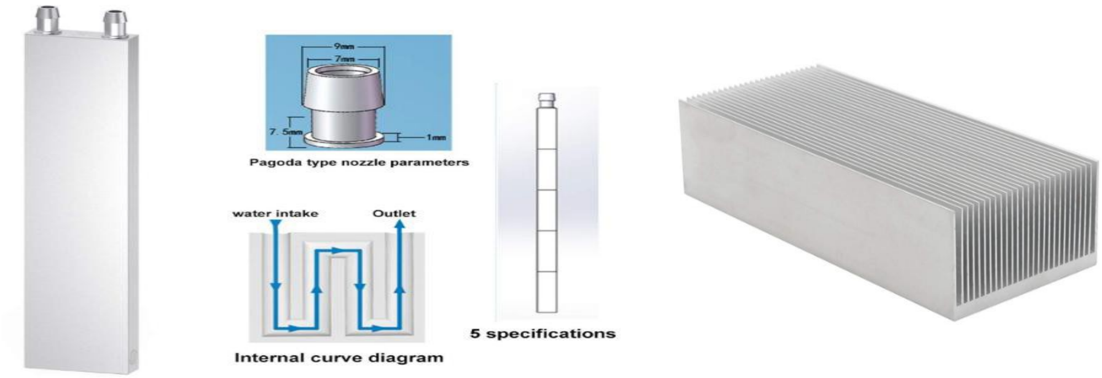


Figure 6. Heat sink and block made of aluminum

Aluminum heat sinks and blocks are used for cooling by reducing the temperature of water. A common and simple use is cooling water in scientific experiments, for example. There are other uses.

2.7 Battery VR 12-150 12V 158Ah

Figure 7. Battery 12V 158Ah

2.8 Hybrid Solar Inverter

A solar inverter photovoltaic (PV) system that converts the direct current (DC) electricity generated by solar panels into alternating current (AC) electricity, which can be used by household appliances or fed into the electrical grid. It acts as the central control unit of the solar power system, ensuring that the energy produced is compatible with standard electrical systems. In addition to power conversion, modern solar inverters also perform important functions such as monitoring system performance, optimizing power output, and protecting the system from faults like overvoltage or short circuits. By efficiently managing energy flow and maintaining stable output, the inverter plays a key role in improving the overall reliability and efficiency of solar power systems.

Figure 8. Hybrid Solar Inverter

2.9 Controller temperature regulator thermostat (STC-1000)

The STC-1000 is a temperature controller and regulator thermostat commonly used in electronic and thermal control applications. It is a digital microprocessor-based device designed to automatically control heating or cooling systems based on a set temperature range defined by the user. The STC-1000 operates by continuously measuring the ambient temperature through a connected NTC temperature sensor. When the temperature rises above or falls below the desired setpoint, it activates either the cooling relay or the heating relay to restore the target temperature. It offers features like easy digital calibration, precise temperature control, and dual relay output, making it a reliable and cost-effective solution for maintaining stable thermal conditions in both industrial and experimental setups.

Figure 9. Controller temperature regulator thermostat(STC-1000)

3. EXPERIMENTAL RESULTS

Solar panels are a clean and common way to convert sunlight into electricity. These panels work using special materials, usually silicon, that generate an electric current when sunlight strikes them. This process is called the photovoltaic effect. However, not all of the sunlight that falls on a solar panel is converted into electricity. In fact, only about 15% to 22% of the sun's energy is converted into usable electricity in most commercial panels. The remaining 78% to 85% is not used for power but is converted into heat. This heat accumulates on the panel and raises its temperature. Herein lies the problem: the hotter the panel gets, the less efficient it is. For every degree Celsius above 25°C (the standard test temperature), a solar panel can lose 0.4% to 0.5% of its efficiency. Therefore, on a hot, sunny day, when the panel temperature may reach 60-70°C, its output can drop by about 15%, leaving the panel's capacity at 128 watts. This is not an easy task for large solar energy systems, especially in limited spaces. While solar panels provide us with clean energy, a significant portion of the sun's energy is wasted as heat, negatively impacting the panels' performance. Therefore, keeping solar panels cool is crucial to maximize their power.

3.1 Methodology and Setup

In this experiment, two solar panels were installed in Tobruk, Libya (32°04'21"N, 23°57'17"E), tilted approximately 32 degrees south to maximize solar radiation. The first panel served as a reference without cooling, while the second panel was equipped with the cooling system under test. Testing was conducted from 10:00 a.m. to 4:00 p.m. during August and September to measure performance under extreme daytime temperatures.

3.1.1 Experiment 1 (Water Cooling)

The water cooling system includes a main water tank, a DC Water Pump, five sprinklers installed along the upper edge of the solar panel and a drainage system in the lower part of the panel . Water is pumped from the tank through the pump to the sprinklers located on the top of the board, passing through the surfaces of the board to the water collection channel, from there to the first tank and then to the heat sink to reduce the heat of the water time to the main tank, creating a simple and efficient recycling system.

We sprayed water and measured the temperatures of the front and rear panels, as well as the abscess of the panel. We noticed a significant decrease in temperature and improvement in the abscess of the plaque. Naturally, the plate heats up gradually. The power output and temperatures of the plate were measured at consecutive times from the moment the water was sprayed until the temperature returned to its state before the cooling process as shown in the following table:

3.1.1.1 First experimental study

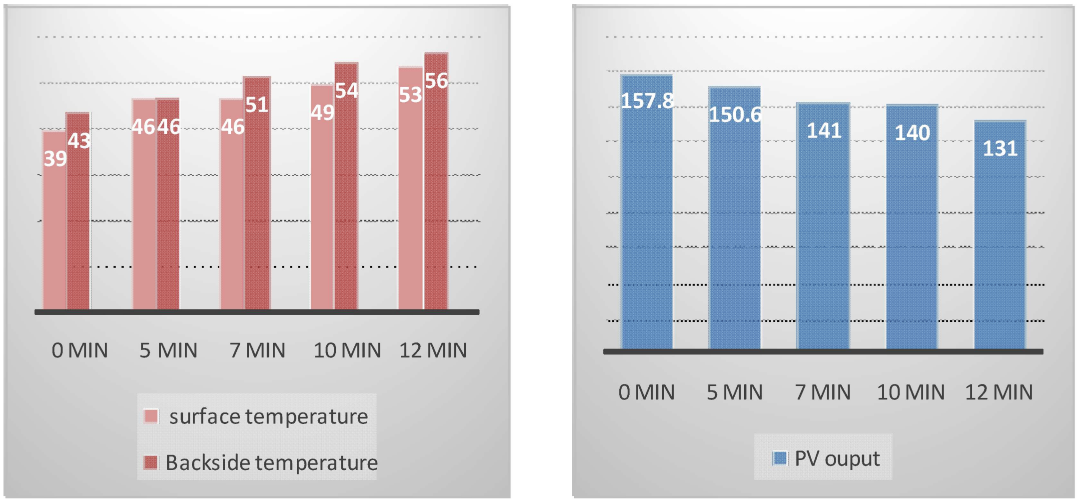
The first experiment on the thirtieth of August was about:
Temperature: 31°C, Wind speed: 08 and Humidity: 52 %

Table 2. Uncooled Solar Panel Results.

Time	0 / min
PV surface temperature	53 C
PV Backside temperature	56 C
PV output	130.4 W
Vmp	19.2
Imp	6.8
Voc	20.6
Isc	8.1

Table 3. Cooled Solar Panel Results.

Time	0/min	5/min	7/min	10/min	12/min
PV surface temperature	39 C	43 C	46 C	49 C	53 C
PV Backside temperature	43 C	46 C	51 C	54 C	56 C
PV output	157.8 W	150.6 W	141 W	140 W	131 W
Vmp	20.5	19.1	19.4	19.2	19.1
Imp	7.7	7.9	7.3	7.1	6.8
Voc	21.6	20.6	20.9	20.9	20.6
Isc	9.1	8.5	8.7	8.5	8.1



(A) (B)

Figure 10. (A) relationship between solar panel temperature and time after the cooling process. (B) Solar panel output rate after the cooling process.

3.1.1.2 Second experimental study

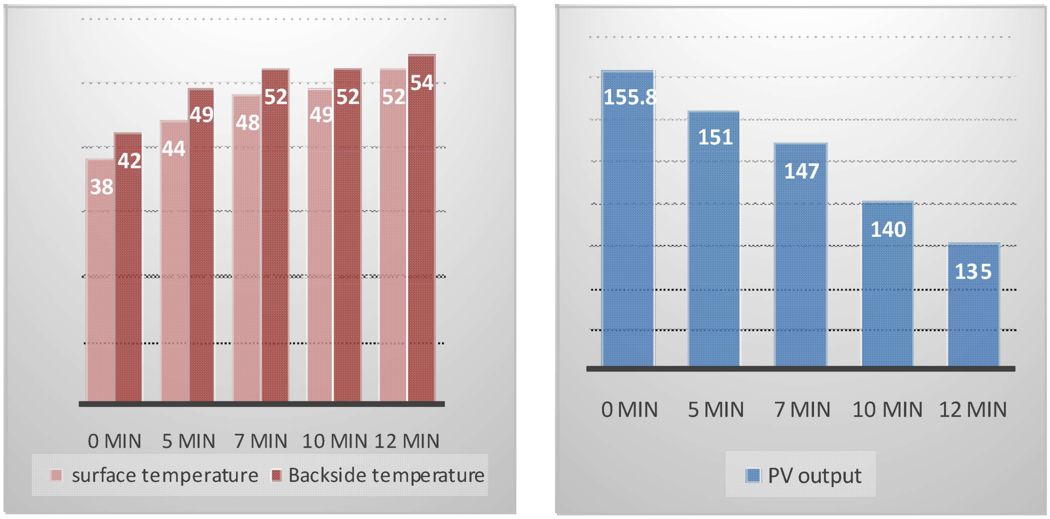
The second experiment was on the seventeenth of September about
Temperature : 30 C, Wind speed : 15 and Humidity : 59 %

Table 4. Uncooled Solar Panel Results Second experimental study.

Time	0/min
PV surface temperature	51 C
PV Backside temperature	54 C
PV output	134.6 W
Vmp	19
Imp	7.1
Voc	20.8
Isc	8.7

Table 5. Cooled Solar Panel Results Second experimental study

Time	0/min	5/min	7/min	10/min	12/min
PV surface temperature	38 C	44 C	48 C	49 C	52 C
PV Backside temperature	42 C	49 C	52 C	52 C	54 C
PV output	155.8 W	151 W	147 W	140 W	135W
Vmp	20.5	19.9	19.4	19.1	19.1
Imp	7.6	7.6	7.6	7.3	7.1
Voc	21.9	21.2	20.9	20.9	20.8
Isc	9.1	9.1	9.1	9	8.9



(A) (B)

Figure 11. (A) relationship between solar panel temperature and time after the cooling process.
(B) Solar panel output rate after the cooling process.

3.1.1.3 Third experimental study

The third experiment was on the seventeenth of October :
Temperature: 31 C, Wind speed: 10 and Humidity: 38 %

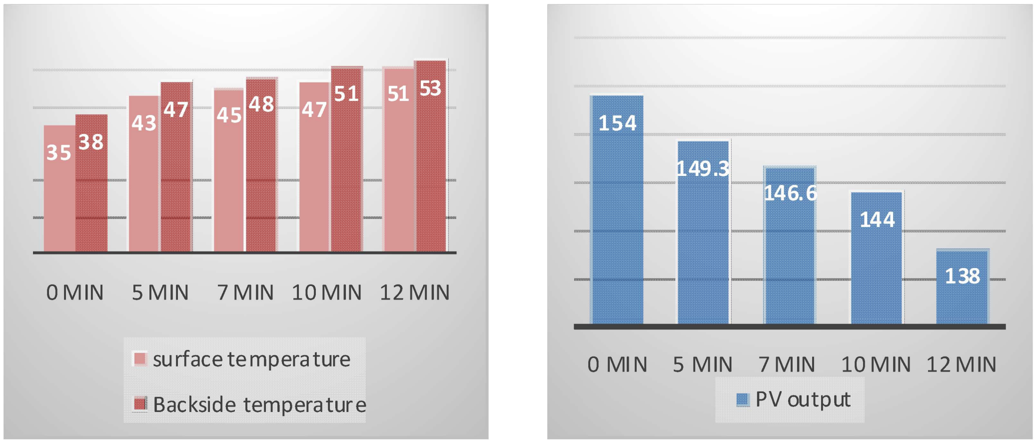
Table 6. Uncooled Solar Panel Results Third experimental study

Time	0/min

PV surface temperature	52 C
PV Backside temperature	54C
PV output	121.5 W
Vmp	19.3
Imp	6.3
Voc	20.5
Isc	7.9

Table 7. Cooled Solar Panel Results Third experimental study

Time	0/min	5/min	7/min	10/min	12/min
PV surface temperature	35 C	43 C	45 C	47 C	51 C
PV Backside temperature	38 C	47 C	48 C	51 C	53 C
PV output	154 W	149.3 W	146.6 W	144 W	138 W
Vmp	20.3	19.4	19.3	19.2	19
Imp	7.6	7.7	7.6	7.5	7.3
Voc	21.9	21.1	21.0	20.9	20.8
Isc	8.2	8.1	8.2	8.2	8.2



(A) (B)

Figure 12. (A) relationship between solar panel temperature and time after the cooling process. (B) Solar panel output rate after the cooling process.

Figure 13. Solar panels used in the experiment

Figure 14. Solar panel output meter reading and temperature after cooling process

As a result of these readings and re-experimenting more than once, I prefer two scenarios for applying this system for several factors that will be mentioned later. The two scenarios are:

Intermittent water spraying has been tried and implemented because of the advantages of this method . The intermittent spraying period reduced the temperature of the panels to below 40 degrees Celsius, which is the right temperature for the best efficiency in solar panel production. The amount of energy consumed by the cooling system, the water used and the cost of setting up the system must be taken into account in order to reach an optimal cooling system .

We will perform calculations on the first pilot study to calculate the amount of energy consumed by the system and the energy produced by the solar panels from then the amount of water and the cost of the system after the cooling process to determine the efficiency of the cooling system from all aspects:

The first condition(Cooling system efficiency)

- **0 min to 7 min**

Cooling power consumption $_{7\text{min}}$ =

$$(3.7\ I \times 12\ V) \times (1/8) = 44.4\ W \times 1/8 = 5.55\ W$$

Cooling-induced energy enhancement $_{7\text{min}}$=

$$\left(\frac{(157.8\ +\ 150.6)}{2} \times 5\right) + \left(\frac{(150.6\ +\ 141)}{2} \times 2\right) - \frac{1062.6}{7} - 151.8\ \text{W}$$

P $_{\text{Cooling-induced energy enhancement 7min}}$ = 151.8 W

Uncooled panel power = 130.4 W

Energy gain rate = (Cooling-induced energy enhancement $_{7\text{min}}$ – Uncooled panel power) – Cooling power consumption $_{7\text{min}}$ = (151.8 W - 130.4 W) – 5.55 W = 15.85 W

Cooling Load Percentage of Solar Output =

$$\frac{5.55\ W}{151.8\ W} \times 100 = 3.6\%$$

- **0 min to 10 min**

Cooling power consumption $_{10\text{ min}}$ = (3.7 I × 12 V) × (1/11) = 44.4 W × 1/11 = 4.036 W

Cooling-induced energy enhancement $_{7\text{min}}$ =

$$\left(\frac{(157.8\ +\ 150.6)}{2} \times 5\right) + \left(\frac{(150.6\ +\ 141)}{2} \times 2\right) + \left(\frac{(141 + 140)}{2} \times 3\right) = \frac{1484.1}{10} - 148.41\ \text{W}$$

P $_{\text{Cooling-induced energy enhancement 10min}}$ = 148.41W

Uncooled panel power = 130.4 W

Energy gain rate = (Cooling-induced energy enhancement $_{\text{10min}}$ – Uncooled panel power) – Cooling power consumption $_{\text{10min}}$=(148.41 W-130.4 W)–4.36 W = 14.374 W

Cooling Load Percentage of Solar Output =

$$\frac{4.036\ W}{148.41\ W} \times 100 = 2.7\%$$

- **0 min to 12 min**

Cooling power consumption $_{\text{12min}}$ = (3.7 I × 12 V) × (1/13) = 44.4 W × 1/13 = 3.4 W

Cooling-induced energy enhancement $_{\text{12min}}$ =

$$\left(\frac{(157.8\ +\ 150.6)}{2} \times 5\right) + \left(\frac{(150.6\ +\ 141)}{2} \times 2\right) + \left(\frac{(141 + 140)}{2} \times 3\right) + \left(\frac{(140 + 130)}{2} \times 2\right) = \frac{1754.1}{12} = 146.175\ \text{W}$$

P $_{\text{Cooling-induced energy enhancement 12min}}$ = 146.17W

Uncooled panel power = 130.4 W

Energy gain rate = (Cooling-induced energy enhancement $_{\text{7min}}$ – Uncooled panel power) – Cooling power consumption $_{\text{12min}}$ = (146.17 W -130.4 W) – 3.4 W =12.37 W

Cooling Load Percentage of Solar Output =

$$\frac{3.4\ W}{146.17\ W} \times 100 = 2.32\ \%$$

The second condition (Water consumption rate)

The measurement of the amount of water used by the sprinkler system was carried out by collecting it in a second tank before pumping it back to the main tank. Our observations have shown that the system consumes about 60 to 100 ml of water per liter sprayed on the plate. This "loss" varies depending on the surrounding conditions, such as high winds or high plate temperatures, which can cause more water to evaporate . The sprinkler system is operated for 1minutes and uses a total of 2 liters of water. Therefore, we can calculate the depreciation rate as follows:

Average water consumption per cooling cycle =

$$\frac{100 + 60}{2} = 80\ ml$$

- **0 min to 7 min**

Number of cooling cycles per hour = 60 min / 8cycle = 7.5 times

$$7.5 \times 80 = 600\ ml$$

- **0 min to 10 min**

Number of cooling cycles per hour = 60 min / 11 cycle = 5.45 ~ 5.5 times

$$5.5 \times 80 = 400\ ml$$

- **0 min to 12 min**

Number of cooling cycles per hour = 60 min / 13 cycle = 4.6 times

$$4.6 \times 80 = 368\ ml$$

The system uses about 600 ml of water per hour which is considered an acceptable rate because it leads to a noticeable improvement in the efficiency of the solar panels achieved through the cooling process.

The second condition(System cost)

The actual price of putting in a cooling device can not be determined, however it's miles noticeably low as compared to different cooling systems, normally now no longer exceeding 20% of the charge of a unmarried sun panel. This percent is calculated primarily based totally on the usage of a few secondhand elements because of the unavailability of latest ones with inside the neighborhood market. This additionally allows to approximate the price of putting in a cooling device inside an present sun energy device, as a excessive cooling device could render the device economically and nearly unviable, especially if there may be area to boom the wide variety of panels. For example, imposing a warmth switch cooling technique the usage of a copper pipe community hooked up at the again of the sun panel is distinctly green and water-saving, however it's also extraordinarily expensive. The price of putting in the copper pipe community may be up to a few instances the charge of a sun panel at the neighborhood market. Therefore, this form of cooling device is taken into consideration economically unfeasible.

Table 8. The output changed with time difference

Time	Cooling-induced energy enhancement	Cooling power consumption	Cooling Load Percentage of Solar Output	Number of cooling cycles per hour
0 min to 7 min	151.8 W	5.55 W	3.6 %	600 ml
0 min to 10 min	148.41 W	4.036 W	2.7 %	400 ml
0 min to 12 min	146.1 W	3.4 W	2.3 %	368 ml

4. CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusion

This study investigated the effectiveness of a water-based cooling system in enhancing the electrical performance of photovoltaic (PV) panels under real-world operating conditions — particularly in hot climates. Experimental results demonstrated a clear and consistent improvement in panel efficiency when active water cooling was applied. On average, the cooled panels showed a 10.5 % increase in power output compared to uncooled (reference) panels, mainly due to the reduction in module temperature — which dropped by 14°C during peak irradiance hours.

The case study applied at the Shraddha test site confirmed these findings: even with modest water flow rates and simple system design, cooling significantly mitigated thermal losses and improved energy yield over the testing period. Importantly, the system proved practical and scalable—requiring low maintenance and using minimal water (especially when a closed-loop or recirculation approach was adopted).These results support the idea that water-based cooling is not just theoretically beneficial, but also feasible and impactful in real applications — especially in regions like ours, where high ambient temperatures frequently limit solar panel performance. While the initial cost and water usage require consideration, the net energy gain and potential long-term reliability improvements make this approach a promising strategy for boosting solar energy efficiency.Future work could explore hybrid cooling methods (e.g., water + phase-change materials), optimize water flow control using smart sensors, or assess economic payback periods in different climatic zones.

4.2 Recommendations for Practical Application and Optimization

We calculated the average energy output for each cooling cycle count, and the results showed excellent performance—particularly after accounting for the cooling system's own power consumption and expressing it as a percentage of the panel's total output, which is crucial for evaluating system viability. Additionally, the average water consumption per cycle was computed to ensure the cooling process was nearly complete and sustainable.

Overall, the intermittent water-spraying cooling method delivered highly satisfactory results during the first few minutes of operation, followed by a gradual temperature rise during the off-period. This behavior was confirmed by prior measurements, which demonstrated a consistent rate of temperature reduction and corresponding improvement in solar panel power output.

A key advantage of this approach Is the ability to control the number of cooling cycles. This control is based on several adjustable parameters fed into the system, which can be categorized as follows:

4.2.1 Number of spraying cycles:

1- 1:7 to make the cycle 1/8 longer; output decreases slightly but still provides good efficiency.
2- 1:10 for a cycle 1/11 solar panel efficiency decreases noticeably but remains within acceptable limits.
3- 1:12 to make the cycle 1/13 in this case, the system restarts each time because the solar panel returns to its temperature before cooling.

4.2.2 Factors determining the number of spraying cycles:

1- The importance of the load from the solar energy system
2- peak time, which also depends on the nature of the loads
3- Climate because it has a direct impact on the performance of the cooling system
4- Water availability.

4.3 Recommendations

4.3.1 Solar panel system installation

- Monocrystalline solar panels are generally preferred in hot climates because they perform better at high temperatures compared to other types, such as polycrystalline panels. These panels are made from a single, pure silicon crystal, which allows for more efficient electricity flow and reduces internal losses. As a result, they can generate more power from the same amount of sunlight.Another important reason is their lower temperature coefficient, meaning their efficiency decreases as the temperature rises. Typically, the temperature coefficient of monocrystalline panels ranges from -0.3% to -0.4% per degree Celsius, while that of polycrystalline panels ranges from -0.5% and above per degree Celsius. For example, if the panel temperature rises by 20 degrees Celsius, a monocrystalline panel might lose only 6–8% of its efficiency, while a polycrystalline panel could lose up to 10%.In addition, monocrystalline panels have a more uniform structure, making them more resistant to the thermal stress caused by the daily heating and cooling cycles common in hot regions. They also tend to perform better in low-light conditions, such as dusty or cloudy days, which are common in desert environments. In short, mono crystalline solar panels are preferred in hot climates because they maintain their high efficiency, are more durable at high temperatures, and offer better overall performance and a longer lifespan than other panel types.

- Maintaining a minimum gap of 5 cm between solar panels is crucial for optimal performance and safety. When solar panels are operating, their temperature rises under sunlight, which can reduce their efficiency. The small gap between the panels allows air to flow freely around and behind them, helping to cool the system naturally. This ventilation reduces panel temperature and helps maintain high efficiency.This gap also allows for thermal expansion and contraction. As the panels and metal frames heat up during the day and cool down at night, they expand and contract slightly. Without this gap, this movement could cause mechanical stress, cracking, or warping over time.Furthermore, this gap helps prevent dust and moisture buildup by allowing rainwater and air to pass through easily. It also greatly simplifies cleaning, inspection, and maintenance.In short, leaving approximately 5 cm between solar panels improves natural ventilation, reduces heat buildup, prevents physical damage from thermal stress, and ensures the long-term durability and stable performance of the solar power system.
- Solar panels should be installed at least one meter above the ground or building's roof for several important performance and durability benefits. This height allows air to circulate freely beneath the panels, improving natural ventilation and helping to lower their operating temperature. Cooler panels operate more efficiently, as higher temperatures can reduce their energy output.Raising the panels also helps prevent heat reflection from concrete or metal surfaces, which can increase panel temperature and shorten their lifespan. Additionally, this height keeps the panels away from dust, sand, and standing water, reducing the risk of corrosion or electrical damage during rain.A one-meter height makes the system easier to clean, inspect, and maintain without disassembling it. It also prevents shading caused by small obstructions, improves safety, and allows for better cable management.

  Keeping solar panels at least one meter above the roof improves airflow, cooling, and hygiene, while protecting the system from heat and humidity. This simple design choice helps maintain higher efficiency and ensures the long-term reliability of the solar power installation.

4.3.2 Cooling system

- The efficiency of a cooling system is judged based on two major factors: first, by the temperature reduction of the panels, and second, by the surrounding environment that greatly affects the system; for instance, while a water-based cooling system would no doubt be efficient in both passive and active systems when compared to an air-based cooling system, its effectiveness is understandably restricted in windy or turbulent climates found on mountain slopes, coastlines, and open plains. On the other hand, using passive air-based cooling systems in low-lying areas with practically no wind, as found between mountains and lowlands, practically nullifies the system. Hence, there is a need to take into consideration not only the climate but also the cooling system itself.
- A solar panel cooling system has to be energy efficient. Energy consumption by the coolers should not be more than 10 % of the total energy generated by the panels, and if possible, far less. It should ideally consume less than 8 %. If it goes over 10 % of the electricity generated, the cooling mechanism will not be a helping factor but a burden on the whole system and consume most of the energy it is supposed to contribute to. The aim is to give more energy compared to what it consumes.

4.3.3 Intermittent water cooling system

- A water-based cooling system would be preferred because it reduces the temperature of the solar panel efficiently as well as maintains cleanliness on its surfaces. This method has been effective in performance compared to other cooling technologies, as it not only maintains panel operating efficiency but also helps extend their lifespan by reducing thermal stress and surface contamination.

- The water spray system should be able to function intelligently based on need for each panel while conserving water. This will be accomplished with an exacting monitoring system based on temperature, wind speed, and water availability. For instance, its spray cycle will be turned on at a ratio of 1:7 in the event of panel temperature greater than 60°C or 1:10 when it is lower, based on the temperature reading from the previous minute of each new cycle. Further, this system will automatically shut down in the case of high winds-excluding southern winds-to prevent unnecessary operation.
- We can make the cooling system even more effective, by combining the water spray with a passive cooling method. To do so, aluminum fins must be added to the rear part of the solar panel. These fins work just like a radiator- when there is a breeze, it naturally helps disperse heat. On very windy days, this is really useful when the water spray becomes less efficient. The good news in the city of Tobruk is that the wind is usually light to moderate. That means for the water system, wind is not a big problem but actually a bonus for these cooling fins since the steady breeze will help them work even better.
- The use of an Arduino to drive an intermittent water cooling system is also highly recommended. This increases its flexibility significantly since you would easily be able to add a number of sensors into the system like a water flow sensor and an anemometer to measure wind movement. These would give you a full view of the operation of the system at any one time. Such information is what you need to make fine adjustments for peak performance and efficiency. Let me add here that this was, in fact, the ideal arrangement. This was, however, not used in this maiden experiment simply because such components were not readily available in the home market at the time of execution.
- An outstanding bonus benefit of employing a water-cooling system is that it naturally serves to clean the solar panels. This is because as water is made to flow or be sprayed across the surface, it washes away dust and bird droppings, among other debris, which tends to build up over time. A clean surface allows sunlight to permeate the glass unobstructed and to reach the solar cells for better performance. In other words, the panel performs not only better since it is cooler but also because it is cleaner, capturing maximum sunlight. These two advantages reduce the frequency of manual cleaning, saving time, water, and effort, while maintaining a consistently higher energy output.

4.4 Further Work

Results obtained in this work are encouraging and open several meaningful avenues for advanced research and practical development. In order to move beyond the proof-of-concept toward real-world deployment, the following directions are recommended:

1- Integration of Smart Control Systems
It is recommended that future work embed intelligent control into the cooling system. For example:
Using IoT-enabled temperature, irradiance, and humidity sensors to feed real-time data into a microcontroller like Arduino or Raspberry Pi.vActive adaptive algorithms like PID control or fuzzy logic can be used to dynamically adjust water flow rate, increasing the cooling action at peak temperatures and reducing or stopping flow under cooler periods or low levels of irradiance Connecting the system to weather forecasts using cloud APIs for advance notice of temperature increases and to proactively pre-cool panels, improving responsiveness and saving water/energy. This

kind of smart integration alone can significantly improve efficiency and reduce the costs of operation, redefining passive cooling as an intelligent thermal management system.

2. Collaboration with PV Manufacturers: Embedded Cooling Solutions

- Currently, most cooling systems are retrofitted externally. The next logical step would be to approach the panel manufacturers and see if they could offer some kind of factory-integrated cooling:
- The design of PV modules with integrated microchannel layers, such as thin copper or aluminum serpentine channels, bonded to the backsheet is similar to heat spreaders in electronics.
- Improvement of lateral heat spreading before it reaches hotspots by using thermally conductive encapsulants or backsheet materials, for example, graphite composites or aluminum nitride films.
- Developing standardized interfaces-for example, quick-connect water ports at the panel edges-to facilitate easy on-site assembly and maintenance, particularly for large farms.

This would decrease installation complexity, improve reliability (no external tubing exposed to weather/ mechanical stress), and might offer possibilities for extending warranty coverage by controlling thermal cycling.

3. Thermally Optimized Panel ArchitectureBesides retrofitting panels with cooling post-production, future panels could be designed from the ground up with heat dissipation in mind:

Reassessing the cell layout regarding cells using half-cut or shingled cells not only in terms of electrical gain but also for better uniformity of heating.

Passive heat-dissipation structures can be integrated, including finned rear surfaces, radiative cooling coatings (emissive in the 8-13 µm atmospheric window), or thermally conductive frames.

Testing the bifacial panels with increased, ventilated backs that would incorporate water cooling together with natural convection.

4. Scalability and Circular Design To ensure sustainability: explore closed-loop, zero-discharge systems using recycled or greywater, perhaps with small-scale solar-powered pumps.

Based on performance-resource balance, evaluate the feasibility in arid regions using evaporative misting with a minimal amount of water or hybrid air-water cooling.Perform techno-economic modeling for various deployment scales, ranging from residential rooftops to utility plants, to determine the most appropriate configurations.

5. Standardization and Certification Finally, the photovoltaic industry lacks standardized testing procedures for actively cooled panels. Future efforts should support developing new IEC or UL guidelines that include: Performance metrics under active cooling - such as "Cooled STC" conditions, Reliability Tests for Thermal Cycling with Fluid Systems Safety protocols concerning water-electrical isolation. Addressing such areas, especially in collaboration between researchers, engineers, and manufacturers, will ultimately enable water-based cooling to transition from its performance-enhancing role to a core feature of next-generation solar technology.

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