

Effect of Water Cooling on Photovoltaic Performance and Efficiency

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Abstract:

Photovoltaic (PV) panels exhibit reduced electrical performance as their surface temperature rises due to direct solar radiation, mainly in hot climates. This study experimentally evaluates the effectiveness of continuous water cooling applied to the back surface of a 50 W polycrystalline PV module in Benghazi, Libya. Measurements of solar irradiance, module surface temperature, open-circuit voltage (Voc), current (I), and maximum power (Pmax) were recorded at 10-minute intervals during peak solar hours under two conditions: without cooling (control) and with continuous water circulation. The water cooling reduced the module temperature by an average of approximately 3 °C, which resulted in a measurable increase in Voc and current. Consequently, the maximum power output increased by about 8% and the overall module efficiency improved by roughly 7% compared to the uncooled condition. The findings indicate that simple water-cooling systems can be a low-cost and effective method to mitigate thermal losses and enhance PV performance in hot regions. Recommendations include testing the approach across different PV technologies and assessing sustainability when water resources are limited.

Keywords: Photovoltaic panels; Water cooling; Solar irradiance; Efficiency improvement; Hot climate.

Introduction

The increasing demand for clean and sustainable energy has positioned solar power as one of the most promising renewable energy sources worldwide. Solar energy is abundant, free, and environmentally friendly, and it can be harnessed directly through photovoltaic (PV) technology. PV systems have become attractive due to their modularity, low maintenance, and ability to provide electricity in both urban and remote areas (Askari et al., 2015; Zeman, 2003).

Despite these advantages, the performance of PV panels is significantly limited by temperature effects. Under real operating conditions, PV modules absorb up to 80% of incident solar radiation, of which only a small fraction is converted into electricity, while the remainder is dissipated as heat (Alami, 2014). This leads to overheating of the modules, which reduces their efficiency and power output. It has been reported that the electrical output of crystalline silicon PV cells decreases by approximately 0.2–0.5% for every 1 °C increase in module temperature (AIP, 2021). Such temperature dependence is a major obstacle to maximizing PV performance in hot climate regions.

Figure 1 illustrates how extracted heat can be utilized in PV/T hybrid systems for beneficial applications.

Various cooling techniques have been proposed to address this challenge, including air cooling, heat pipe systems, hybrid photovoltaic/thermal (PV/T) systems, and water cooling (Ceylan & Ilhan, 2014; Teo et al., 2012). Among these, water cooling has gained considerable attention due to its simplicity, effectiveness, and dual potential for electricity enhancement and thermal energy recovery. Previous studies reported performance improvements ranging between 7–15% with water-based cooling methods (Moharram et al., 2013; Bahaidarah et al., 2013).

This study aims to experimentally investigate the impact of water cooling on PV panel performance in Benghazi, Libya. Specifically, it evaluates the extent to which water cooling can reduce surface temperature, enhance

efficiency, and increase electrical output. The findings are expected to provide practical insights into improving the feasibility and reliability of PV systems in hot climate regions.

As shown in Figures 2 and 3, both voltage and efficiency decrease with increasing temperature, which highlights the need for cooling methods. In addition, Figure 1 illustrates how PV/T systems can utilize extracted heat for beneficial applications.

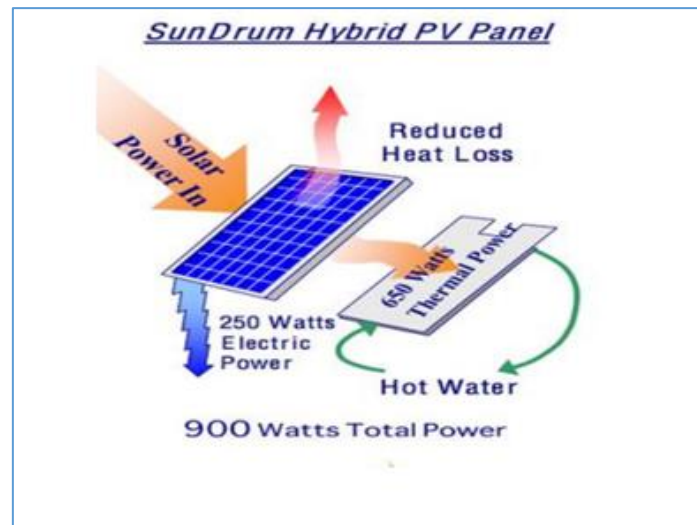


Figure 1. Utilization of extracted heat for beneficial use (PV/T systems).

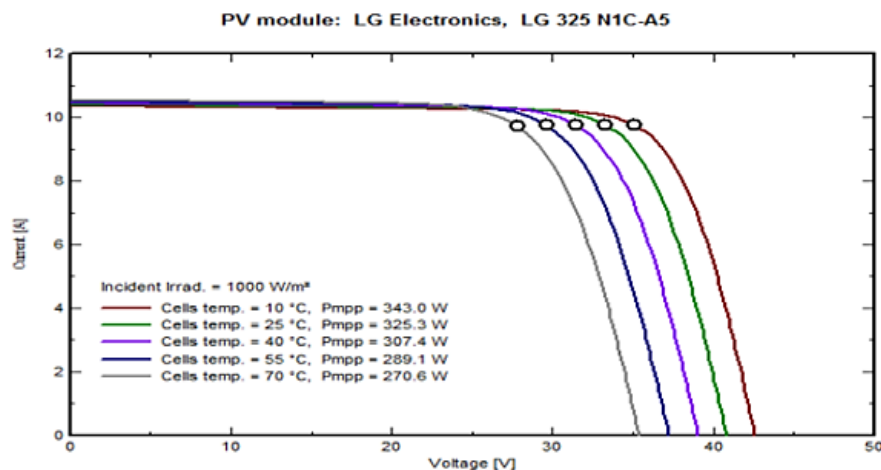


Figure 2. The voltage decreases as temperature increases.

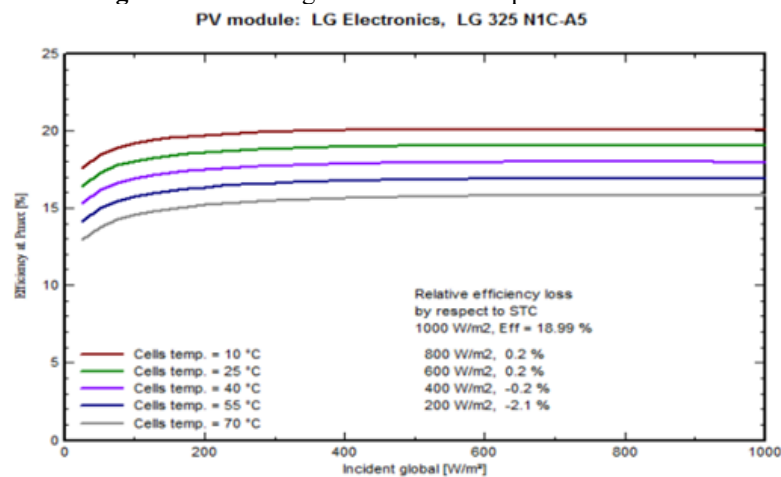


Figure 3. The efficiency decreases as temperature increases.

2. Methodology

2.1 Study Location

The experimental study was conducted in Benghazi, Libya, specifically in the Budresa/Nawakiyya area, located about 15 km from the city center. The site was chosen due to its open terrain and minimal shading or obstructions, which ensures high solar radiation exposure. Benghazi lies at latitude 32.11°N and longitude 20.07°E , with an elevation of approximately 3 meters above sea level. The geographical location of the experimental site is shown in Figure 4. A closer view of the Budresa/Nawaghiya area is provided in Figure 5.



Figure 4. The study location on the outskirts of Benghazi (15 km).



Figure 5. The study location in Budresa/ Nawaghiya rea.

2.2 Experimental Setup

The experiment was designed to evaluate the effect of water cooling on the performance of photovoltaic (PV) panels. A 50 W polycrystalline PV module was used, tested under two conditions:

1. **Without cooling (control condition):** The module was left to operate under natural conditions.
2. **With water cooling:** A continuous flow of water was applied across the back surface of the PV panel using a simple piping system connected to a water tank.

Figure 6 shows the relationship between temperature rise and wind speed

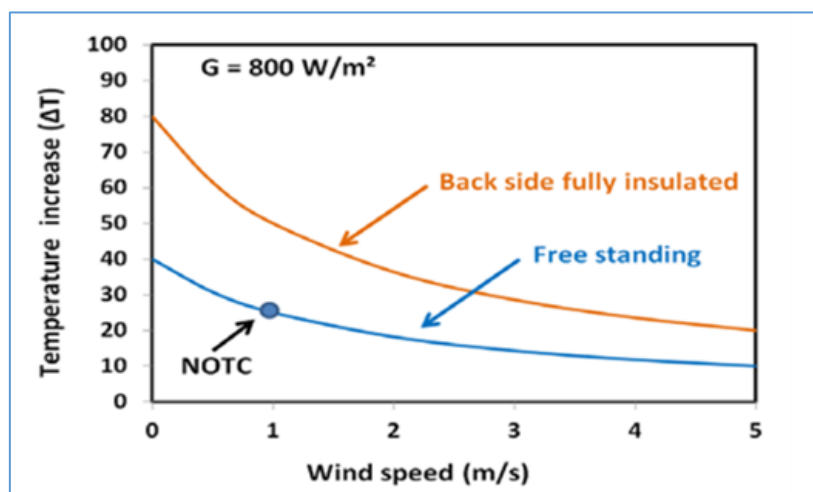


Figure 6. Temperature–Wind speed curve.

Figure 7 illustrates how module temperature increases with irradiance for different module constructions.”

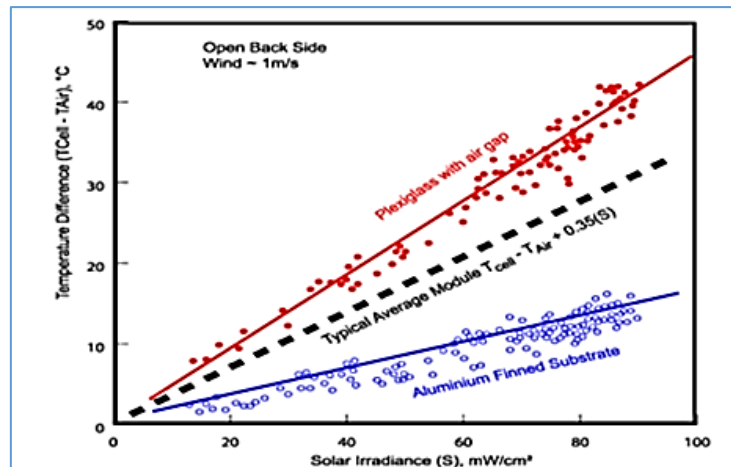


Figure 7. Temperature increases with solar irradiance for different module types.

2.3 Measurement Instruments

The following instruments and devices were employed to collect experimental data:

- **Digital thermometer:** to measure PV surface temperature. The thermometer used on-site is shown in Figure 8.
- **Solar power meter:** to record incident solar irradiance (W/m^2).
- **Multimeter devices:** to measure open-circuit voltage (V_{oc}), current (I), and electrical power (P).
- **Water tank and circulation system:** to provide controlled water flow across the panel.



Figure 8. Thermometer measuring module temperature on site.

A photograph of the PV setup is presented in Figure 9.



Figure 9. On-site solar PV system.

2.4 Data Collection Procedure

Measurements were taken at **10-minute intervals** between 11:30 a.m. and 12:30 p.m., representing peak solar radiation hours. For both operating conditions (with and without water cooling), the following parameters were recorded:

- Solar irradiance (W/m²).
- PV surface temperature (°C).
- Water inlet and outlet temperatures (°C).
- Open-circuit voltage (Voc), current (I), and output power (P).

2.5 Performance Evaluation

The panel efficiency was calculated using the standard equation:

$$\eta = \frac{P_{max}}{(EX A)}$$

Where:

- η = PV module efficiency,
- P_{max} = maximum power output (W),
- E = solar irradiance (W/m²),
- A = module surface area (m²).

Comparisons between cooled and uncooled conditions were carried out to determine the improvement in performance. Statistical analysis of temperature reduction and corresponding efficiency gains was performed to validate the results.

3. Results

The performance of the photovoltaic (PV) panel was assessed under two conditions: without cooling (control) and with water cooling. Measurements were recorded at 10-minute intervals during peak solar radiation hours.

3.1 PV Performance Without Cooling

Table 1 shows the results of the PV module performance without cooling. The surface temperature increased steadily with solar irradiance, reaching more than 50 °C. Despite relatively stable open-circuit voltage (Voc), the power output remained limited due to thermal effects.

Table 1. PV measurements without cooling.

Time	Solar Intensity (W/m ²)	Panel Temp (°C)	Voc (V)	Current (A)	Power (W)
11:30	925	40.0	20.3	2.01	29.06
11:40	890	39.7	20.2	2.20	34.44
11:50	938	35.5	20.1	2.13	33.05
12:00	940	42.7	20.3	2.20	33.29
12:10	935	48.2	20.4	2.22	32.10
12:20	920	52.1	20.2	2.22	34.50

3.2 PV Performance with Water Cooling

Table 2 presents the performance of the PV module with continuous water cooling applied to the back surface. Cooling reduced the panel's temperature by an average of 3 °C. As a result, both current and power output increased compared to the uncooled condition. Figure 10 compares maximum power output under cooled and uncooled conditions. Figure 11 shows the efficiency changes between the two test conditions. Figure 12 summarizes the efficiency improvement achieved through water cooling.

Table 2. PV measurements with water cooling

Time	Solar Intensity (W/m ²)	Panel Temp (°C)	Water Tank Temp (°C)	Inlet Temp (°C)	Outlet Temp (°C)	Voc (V)	Current (A)	Power (W)
11:30	925	38.5	27.9	30.2	30.9	20.46	2.74	31.50
11:40	890	34.6	33.5	34.1	34.4	20.43	2.70	34.22
11:50	938	33.0	35.6	34.5	35.4	20.50	2.14	35.10
12:00	940	40.0	32.1	36.7	38.9	20.55	2.17	36.50
12:10	935	46.0	33.5	33.7	36.5	20.50	2.20	36.70
12:20	920	50.0	34.6	37.5	40.8	20.56	2.40	37.45

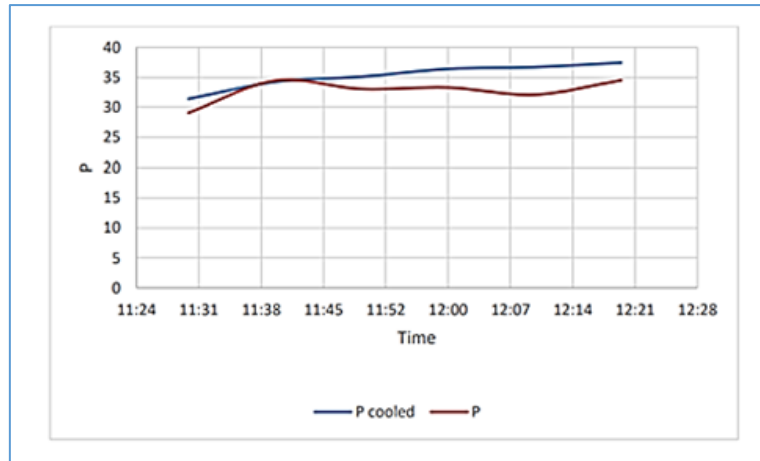


Figure 10. Variation of Pmax with and without water cooling.

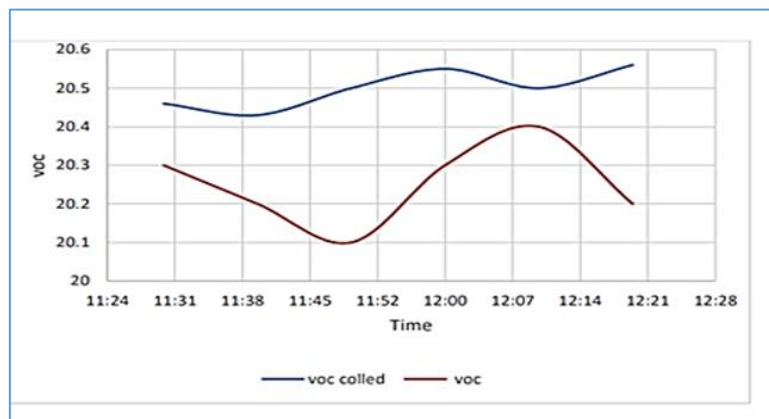


Figure 11. Variation of efficiency with and without water cooling.

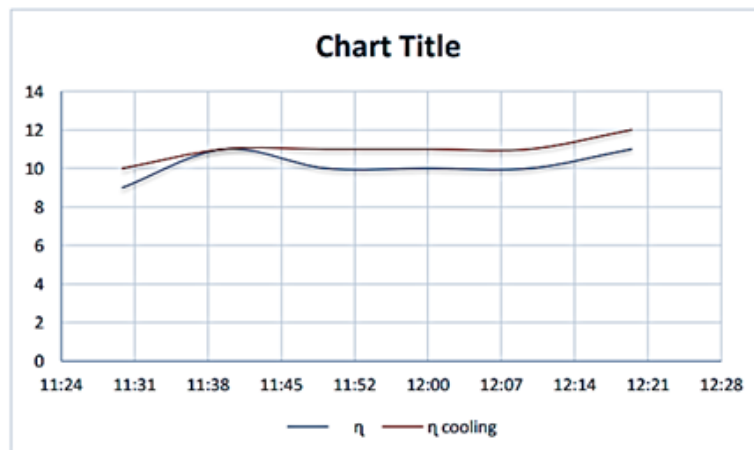


Figure 12. Variation of η (efficiency) with and without cooling.

3.3 Comparative Analysis

A comparison between the two operating conditions revealed the following improvements due to water cooling:

- **Panel temperature:** Reduced by $\sim 3^\circ\text{C}$ on average.
- **Voc:** Increased slightly ($\sim 0.25\text{ V}$).
- **Power output:** Increased by $\sim 8\%$.
- **Efficiency:** Improved by $\sim 7\%$.

These results demonstrate that even a modest reduction in temperature can yield noticeable improvements in PV performance.

4. Discussion

The results of this study clearly demonstrate the significant impact of temperature on the performance of photovoltaic (PV) panels. Under uncontrolled conditions, the panel surface temperature exceeded 50 °C, which limited power output despite stable solar irradiance levels. This finding aligns with earlier studies reporting that PV modules lose between 0.2% and 0.5% of power for every 1 °C increase in operating temperature (AIP, 2021). When water cooling was applied, the module temperature decreased by approximately 3 °C on average. This reduction led to measurable gains in electrical performance: the open-circuit voltage (Voc) increased by around 0.25 V, while the overall power output improved by about 8%. Similarly, efficiency was enhanced by nearly 7%. These improvements, although modest in numerical value, are significant in practical terms, particularly for large-scale PV installations where cumulative efficiency gains translate into substantial energy and cost savings.

The present results are consistent with previous experimental findings. For instance, Moharram et al. (2013) reported that water spraying improved PV output by reducing module temperature, while Bahaidarah et al. (2013) achieved a 9% efficiency increase using a back-surface water cooling technique. In addition, Teo et al. (2012) demonstrated that hybrid photovoltaic/thermal systems with air cooling could enhance efficiency by approximately 14%. The outcomes of the current study fall within this range, confirming the effectiveness of cooling strategies, particularly in hot climates.

A noteworthy contribution of this study is its contextual relevance to the Libyan climate, where high solar irradiance combined with elevated ambient temperatures poses a persistent challenge for PV performance. The findings emphasize that even simple, low-cost cooling methods, such as continuous water circulation, can mitigate thermal losses and improve overall system reliability. However, practical considerations such as water availability and system maintenance must be addressed before large-scale implementation.

The improvements observed in Figures 11–13 confirm the findings of previous studies such as Moharram et al. (2013) and Bahaidarah et al. (2013), which also reported efficiency gains with water cooling.

In summary, the study confirms that water cooling is a technically viable and economically practical approach to improving PV efficiency in hot climates. It also highlights the potential for integrating cooling systems into future PV installations to maximize energy yield and system sustainability.

5. Conclusion and Recommendations

5.1 Conclusion

This study investigated the effect of water cooling on the performance of photovoltaic (PV) panels under the climatic conditions of Benghazi, Libya. The results demonstrated that panel temperature plays a critical role in determining PV efficiency. Under normal conditions, the module experienced significant heating, which reduced power output and overall efficiency.

The application of a simple water cooling system lowered the PV surface temperature by an average of 3 °C. This modest reduction resulted in notable improvements: open-circuit voltage increased slightly, power output rose by about 8%, and efficiency improved by approximately 7%. These findings confirm that water cooling is an effective, low-cost, and practical method for enhancing PV performance, particularly in hot climate regions.

Overall, the study highlights the potential of integrating simple cooling techniques into PV systems to maximize energy yield, improve system reliability, and strengthen the economic feasibility of solar energy projects.

5.2 Recommendations

Based on the findings, the following recommendations are suggested:

1. **Broader Testing:** Future experiments should be conducted across different climatic regions and with various PV technologies (e.g., monocrystalline, thin-film) to validate the results.
2. **Hybrid Applications:** Water cooling can be integrated with photovoltaic/thermal (PV/T) systems to simultaneously generate electricity and recover heat for domestic or industrial use.
3. **Water Sustainability:** In arid areas, recycled or non-potable water sources should be utilized to ensure sustainable operation of cooling systems.
4. **Long-Term Evaluation:** Further studies should focus on the durability, maintenance, and cost-effectiveness of water cooling systems when applied on a larger scale.

These recommendations provide a pathway for optimizing PV system performance in hot climates and encourage further research to advance the practical application of solar energy technologies.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare that they have no conflict of interest.

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