



Design and Build Active Cooling Methods Based on a Water Spray System to Enhance the Performance of Solar PV

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Abstract. The efficiency of solar photovoltaic (PV) systems significantly decreases as the surface temperature of the panels increases due to prolonged solar radiation. This study aims to enhance the performance of solar PV by implementing an active water spray cooling system. The system utilizes a series of nozzles controlled by a thermostat to spray water when the surface temperature reaches 40°C and stops at 30°C. Experimental tests were conducted by comparing PV panel performance with and without the cooling system in open environmental conditions. The results demonstrated that the water spray system effectively reduced the average surface temperature from 50.47°C to 33.97°C, resulting in a power output increase from 88.48 W to 112.36 W and efficiency enhancement from 13.83% to 23.38%. These findings suggest that the proposed active cooling method significantly improves PV performance and supports the use of clean energy, particularly in tropical regions like Bali.

Keywords: Active Cooling, Efficiency, Renewable Energy, Solar PV, Water Spray

1 Introduction

Solar cells, solar panels, or solar photovoltaic (Solar PV) systems are devices that generate electricity from sunlight. In terms of electricity generation, solar panels are influenced by several factors, including the type of PV material, environmental conditions such as temperature, wind speed, and humidity (Faheem et al., 2024). Solar panels experience a decrease in efficiency when their surface temperature rises due to excessive exposure to solar radiation. The application of active cooling systems, such as water cooling, air cooling, or hybrid systems, can help reduce the surface temperature of the panels, thereby improving performance and output power. Passive cooling typically uses phase change material (PCM) as a medium to absorb heat from the solar panel surface. Several studies have been conducted, such as the use of organic PCM on monocrystalline solar panels, resulting in a temperature reduction of 6–9°C and a 2% increase in solar panel efficiency (Waqas et al., 2019). The combination of Al₂O₃/PCM and water showed higher solar cell power output than water cooling alone. This indicated that developing a hybrid cooling model is achievable and produces superior outcomes; however, the system components will be slightly more complex (Salem et al., 2019). Another research on the passive cooling method has been done by Wu and

Xiong (2014), and the result indicated that the passive cooling method was suited to control the surface temperature of solar PV. Similar research on using PCM as a passive cooling method in PV cooling yielded a similar result, indicating that the use of PCM on the back surface of solar PV will increase the performance of solar PV (Chavan & Devaprakasam, 2018; Naseer et al., 2019; Sheikh et al., 2024).

In addition to passive cooling methods, active cooling methods have also been developed to cool the surface of solar cells, including the use of Peltier cells. The results showed that the use of up to 5 TEC units could reduce the surface temperature of the solar panel and increase the power output of the solar panel by up to 7.21% (Azmi et al., 2023). The use of TEC combined with forced cooling using airflow can enhance the cooling effectiveness of the TEC, which is an advantage in terms of the performance of the TEC as a cooler (Enasel et al., 2023). Besides the active approach employing TEC, there are several other active cooling methods, such as using a water-cooling system. Several studies using water cooling systems have been developed. Meng & Lee (2021) developed a solar panel surface cooling system using water circulation, and the results indicated that the system can increase the power output by about 0.45 W and efficiency by about 7.76%. Similar results were also found by (Singh et al., 2024) using a hybrid water-cooling system, where the results indicated that the system can boost the module's output power, and the PV cell lifetime was extended.

In addition to cooling, the water spray system can also remove dust and particulate matter from the panel surface, improving light absorption and reducing soiling losses—a particularly relevant advantage in regions prone to airborne dust, pollution, or agricultural debris. Despite these advantages, there is still limited experimental research focusing on optimizing water spray cooling for PV systems in tropical climates, including its operational scheduling, water consumption efficiency, and long-term effects on panel durability. Furthermore, most existing studies are either conducted in dry climates or under laboratory conditions, making it unclear how such systems perform in humid, high-radiation environments typical of equatorial regions.

The objective of this research is to develop, execute, and assess a water spray cooling system for solar panels in authentic tropical outdoor environments, as indicated by the aforementioned study. The study will evaluate the practicality of the method for large-scale and long-term implementations, as well as quantify the impact of this system on surface temperature reduction, electrical output, and overall efficiency. The results are anticipated to facilitate the creation of cooling solutions that are both cost-effective and readily deployable, and that improve the reliability and performance of PV installations in tropical regions. This is of paramount importance in order to promote the utilization of renewable energy in tourist destinations in Bali, which have historically been reliant on conventional electricity.

2 Methodology

In this research, a novel active cooling system based on water spray has been developed. The schematic of the system is shown in Figure 1.

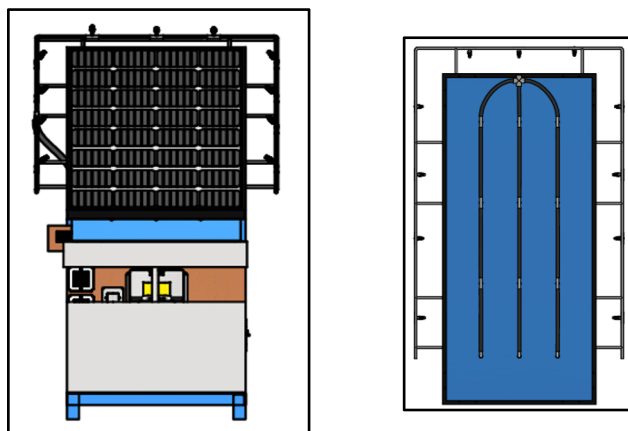


Figure 1. Schematic of Cooling System

The cooling system developed consists of a total of 11 nozzles to spray water onto the surface of the solar panel. There are 4 nozzles on both sides and 3 nozzles on the top of the solar panel. Water is distributed from the storage tank using a DC pump connected to a thermostat on the underside of the solar panel, which controls the timing of water spraying by the nozzles. The nozzles will spray water when the surface temperature of the solar panel reaches 40°C and will stop spraying water when the surface temperature of the solar panel reaches 30°C. The schematic of the water sprayer control is shown in Figure 2, and the specification of the system is shown in Table 1.

Table 1. Specification of Cooling System

No.	Component	Specification
1	LED lamp	10 watt
2	DC Pump	12 V
3	AC/DC Adapter	12 V
4	Inverter	500 W
5	Thermostat	220 V / 1500 W
6	Black/red small wire	NYZ 2 x 23 Zigno
7	Red wire	300/400 V
8	Black wire	300/400 V
9	Wattmeter	100 A
10	MCB	DC 16 A

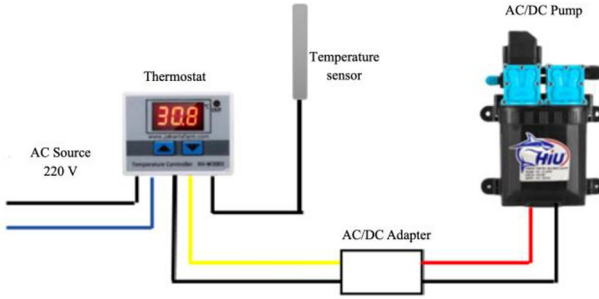


Figure 2. Schematic of Water Spray Thermostats

3 Result and Discussion

3.1 Result

Photovoltaic solar panels, both with and without cooling systems, were evaluated in an open environment. The tests were performed from 2:00 p.m. to 4:00 p.m. GMT+8. A digital multimeter was employed to assess the output current and voltage, a K-type thermocouple to measure the surface temperature, and an environmental measurement instrument to evaluate parameters such as ambient temperature and light intensity. Table 2 presents the performance data of the PV solar panels without a cooling system, and Table 3 presents the performance data of solar PV with a water spray cooling system.

The power input (P_{in}) of the solar panel can be calculated using the formula:

$$P_{in} = I_{rad} \times A \tag{1}$$

where:

- P_{in} = Power input to solar PV (W)
- I_{rad} = Light intensity (W/m^2)
- A = solar PV cross-sectional area (m^2)

The power output (P_{out}) of the solar panel performance is calculated using the formula:

$$P_{out} = V_{pv} \times I_{pv} \tag{2}$$

where:

- P_{out} = Power output (W)
- V_{pv} = Output solar PV voltage (V)
- I_{pv} = Output solar PV current (A)

The efficiency of solar panels is calculated using the formula

$$\eta_{pv} = \frac{P_{out}}{P_{in}} \times 100\% \tag{3}$$

Table 2. Solar PV Performance Without Cooling System

Times Menit	Output solar PV Volt Ampere		Surface temp. T _{pv} (°C)	Ambient		Power		Efficiency %
				Temperature	Light intensity	P _{in}	P _{out}	
				T _a (°C)	W/m ²	W	W	
5	12.33	9.71	45.5	30	647.81	642.36	119.72	18.63
10	12.41	7.31	46.8	30	560.91	556.19	90.71	16.31
15	11.12	7.91	49.3	30	616.22	611.04	87.95	14.39
20	11.62	6.37	50.5	31	695.21	689.37	74.01	10.73
25	12.15	5.89	48.2	29	600.42	595.37	71.56	12.01
30	13.12	6.32	48.2	30	553.11	548.46	82.91	15.11
35	12.13	7.54	49.5	31	861.14	853.9	91.46	10.71
40	11.43	7.39	48.7	29	687.32	681.54	84.46	12.39
45	12.23	7.72	48.9	29	379.22	376.03	94.41	25.1
50	11.12	8.03	51.3	31	742.61	736.37	89.29	12.12
55	11.13	8.38	51.6	31	876.95	869.58	93.26	10.72
60	11.85	9.05	53.5	31	932.23	924.39	107.24	11.6
65	11.02	7.47	52.9	31	608.31	603.21	82.31	13.64
70	11.94	8.04	54.7	31	861.12	853.88	95.99	11.24
75	11.53	6.59	54.1	31	529.32	524.87	75.98	14.47
80	11.52	8.69	53.2	30	655.71	650.2	100.11	15.39
85	11.31	7.61	53.1	30	600.43	595.38	86.06	14.4
90	11.33	7.51	51.3	30	600.43	595.38	85.08	14.29
95	11.78	7.53	50.3	30	624.11	618.86	88.7	14.33
100	11.32	7.53	49.3	30	726.82	720.71	85.24	11.82
105	11.19	6.97	51.4	30	639.92	634.54	77.99	12.29
110	12.4	6.67	49.2	30	592.55	587.57	82.7	14.07
115	12.23	7.39	50.2	30	703.12	697.21	90.38	12.96
120	11.95	7.19	49.8	30	663.65	658.07	85.92	13.05
Mean	11.75	7.53	50.47	30.79	664.94	659.35	88.48	13.83

Table 3. Solar PV Performance with Water Spray System

Time	Output solar PV		Surface temp.	Ambient		Power		Efficiency
				Temperature	Light intensity	P _{in}	P _{out}	
Minutes	Volt	Ampere	T _{pv} °C	T _a °C	W/m ²	W	W	%
5	17.78	6.41	33.4	29	505.6	501.35	113.96	22.73
10	17.07	7.46	34.0	29	497.7	493.51	127.34	25.8
15	17.45	5.40	36.4	29	474.0	470.01	94.23	20.04
20	17.47	6.43	35.4	29	513.5	509.18	112.33	22.06
25	17.06	4.63	29.6	29	466.1	462.18	78.98	17.08
30	17.05	7.71	30.5	29	489.8	485.68	131.45	27.06
35	16.74	6.76	35.0	29	474.0	470.01	113.16	24.07
40	16.01	5.62	37.0	29	474.0	470.01	89.97	19.14
45	17.63	7.51	34.5	29	513.5	509.18	132.4	26.00
50	15.51	7.51	34.4	29	513.5	509.18	116.48	22.87
55	17.6	7.59	33.5	29	497.7	493.51	133.58	27.06
60	17.01	5.56	34.7	29	442.4	438.68	94.57	21.55
65	17.12	7.46	36.8	29	474.0	470.01	127.71	27.17
70	17.32	7.26	34.3	29	474.0	470.01	125.74	26.75
75	17.03	6.82	35.2	29	481.9	477.85	116.14	24.30
80	17.80	7.30	30.7	29	474.0	470.01	129.94	27.64
85	17.77	6.82	35.2	29	474.0	470.01	121.19	25.78
90	17.28	7.02	32.1	29	481.9	477.85	121.30	25.38
95	17.09	6.64	34.5	29	497.7	493.51	113.47	22.99
100	17.17	6.68	36.3	29	474.0	470.01	114.69	24.40
105	16.32	4.19	30.7	29	513.5	509.18	68.38	13.42
110	17.82	6.65	34.2	29	474.0	470.01	118.50	25.21
115	17.02	6.02	34.5	29	474.0	470.01	102.46	21.79
120	17.01	5.81	32.5	29	474.0	470.01	98.82	21.02
Mean	17.18	6.59	33.97	29	484.53	480.46	112.36	23.38

3.2 Discussion

Based on the data and calculations acquired from the solar PV test results, the data is input into a graph to analyze the performance of cooling systems that have been built using a water sprayer. The solar PV voltage output is shown in Figure 3.

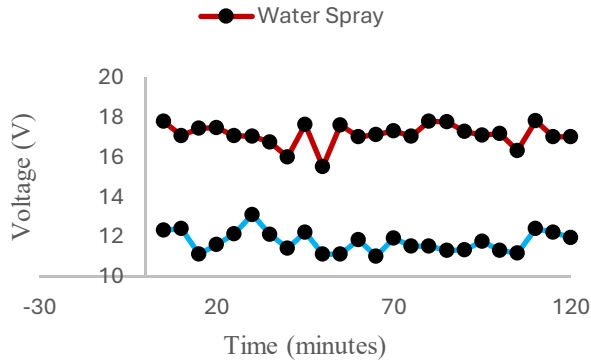


Figure 3. Voltage Output of Solar PV

The voltage produced with water spray is greater than that without cooling. In the absence of cooling, the average overall voltage exceeds 14.12 V. Simultaneously, with the application of water spray cooling, the average overall voltage exceeds 16.99 V. The open-circuit voltage of solar panels is greatly affected by temperature. Research shows that an increase in the surface temperature of solar panels results in a decrease in voltage (Voc). This is because an increase in temperature can reduce voltage and lower the band gap of semiconductors.

The power output and the efficiency of solar PV are shown in Figures 4 and 5. From Figure 4, it can be seen that the average output power generated without a cooling system is 88.48 watts. The use of water spray cooling produces the highest average output power, which is 112.36 watts. This is because during the cooling process, the surface temperature is maintained, causing the solar panel to produce a larger output power.

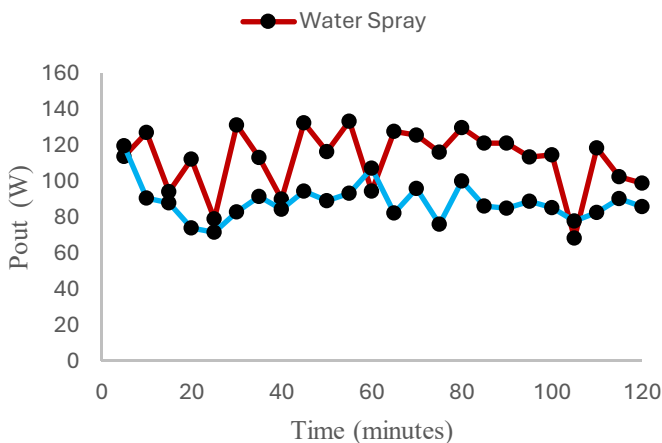


Figure 4. The Power Output of Solar PV

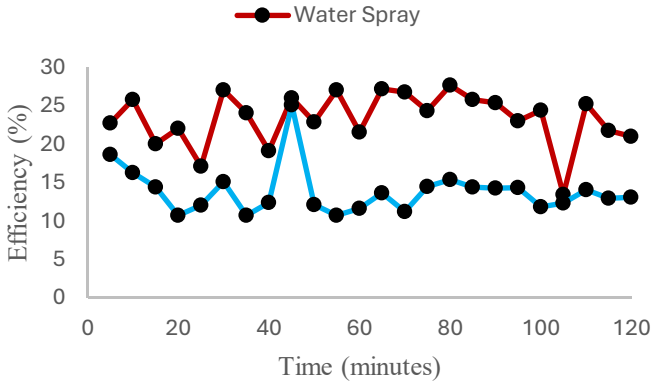


Figure 5. The Efficiency of Solar PV

From Figure 5, it is evident that the average efficiency was achieved over two hours through various test variations. In tests without cooling, the average efficiency produced was 13.83%. The use of water spray cooling resulted in the highest average efficiency, at 23.38%. Since the input power generated by the solar panels is quite large, the increase in efficiency achieved is relatively low. This is because efficiency is the result of dividing the input power by the output power, and with a low increase in efficiency, the result of the division decreases. Since the average efficiency value is higher, the water spray cooling process is better than one without a cooling system; therefore, the use of water spray as a coolant for solar panels has the advantage of maximizing the performance of the solar panels. Table 4 below illustrates several comparisons of test results from various solar PV cooling methods.

The thermostat-controlled water spray system in this study achieved the lowest surface temperature ($\sim 33.97^{\circ}\text{C}$) and highest efficiency gain (+9.55%) among single-method cooling approaches. Its strong performance stems from combined evaporative and convective cooling, plus surface cleaning, with simple control and minimal parasitic energy use, though it requires a steady water supply and may risk corrosion.

Azmi et al. (2020) achieved +8–14% efficiency with back-surface water flow, offering continuous cooling and water reuse but at the cost of pumps and plumbing complexity. Faheem et al. (2018) reported +9–10% gains using TEC, benefiting from compactness but limited by parasitic load and heat sink needs. Waqas et al. (2017) showed a +2–13% improvement with passive PCM cooling, which uses no power but suffers thermal saturation. Singh et al. (2019) simulated a hybrid PCM-water system reaching up to +18% gain, though its complexity and maintenance make it less practical.

Overall, this study's water spray method outperformed other single-method systems in efficiency improvement while remaining simpler than hybrid designs, making it suitable for tropical PV applications with accessible water resources.

Table 4. Comparison of Several Solar PV Cooling Methods

Ref.	Test condition	Cooling method	Surface temperature	Efficiency gain	Advantages	Limitations
This study (Water Spray)	Outdoor, Bali Selatan-Indonesia	Thermostat-controlled water spray (ON 40°C / OFF 30°C)	~ 33.97°C	+9.55% (13.83% → 23.38%)	Large ΔT , low cost, removes dust, simple control	Requires a water source, possible corrosion risk
Azmi et al. (2020)	Outdoor, Malaysia	Back-surface water flow	~ 40.2°C	+8–14%	Continuous cooling, reusable water	Pump energy cost, plumbing complexity
Faheem et al. (2018)	Indoor, simulated	Thermoelectric cooling (TEC)	~42.5°C	+9–10%	Compact, no fluids, modular	Parasitic electrical load, heat sink needed
Waqas et al. (2017)	Outdoor, Pakistan	PCM (paraffin) passive cooling	~ 42 - 47°C	+2–13%	No power use, simple	Thermal saturation, heavy mass
Singh et al. (2019)	Computational simulation	PCM + water cooling	~ 45°C	Up to +18%	Combines the advantages of PCM & water	High complexity, maintenance-intensive

4 Conclusion

Based on the aforementioned examination of solar PV performance, it can be concluded that the design of the solar PV cooling system using a water spray system can function effectively. The average surface temperature using a cooling system is about 50.47°C, and using a water spray cooling system, the temperature decreases by about 32% to 33.97°C. The average power output of solar PV increases with the addition of a cooling system to solar PV. The increase is about 21.25% from 88.48 watts without a cooling system to 112.36 watts using a water spray cooling system. The efficiency of solar PV is also similar, increasing, i.e, the efficiency without a cooling system is about 13.83% and using a water spray system, the efficiency increases to 23.38%.

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References

Azmi, M. S. F. M., Hussain, M. H., Rahim, S. R. A., Mid, E. C., Shaari, A. S., Hashim, N., Husny, N., & Ahmad, M. F. (2023). Hybrid cooling system for solar photovoltaic panel.

- Journal of Physics: Conference Series*, 2550(1). <https://doi.org/10.1088/1742-6596/2550/1/012004>.
- Chavan, S. V. & Devaprakasam, D. (2018). Improving the performance of solar photovoltaic thermal systems using phase change materials—Review. *International Journal of Advanced Science and Engineering*, 4(3), 687. <https://doi.org/10.29294/ijase.4.3.2018.687-697>.
- Enasel, E., Lupu, A.-G. & Dumitrascu, G. (2023). Design and development of cooling systems for PV cells performance improvement. *Bulletin of the Polytechnic Institute of Iași. Machine Constructions Section*, 69(2), 71–84. <https://doi.org/10.2478/bipcm-2023-0016>.
- Faheem, M., Abu Bakr, M., Ali, M., Majeed, M. A., Haider, Z. M., & Khan, M. O. (2024). Evaluation of efficiency enhancement in photovoltaic panels via integrated thermoelectric cooling and power generation. *Energies*, 17(11). <https://doi.org/10.3390/en17112590>.
- Naseer, A., Ali, H., Ahmed, A., Awan, A. & Ali, H. M. (2019). Experimental investigation of photovoltaic panel thermal management using hybrid PCMs. Proceedings book of the fifth international conference on advances in experimental investigation of photovoltaic panel thermal management using hybrid PCMs. <https://www.researchgate.net/publication/338230563>.
- Salem, M. R., Elsayed, M. M., Abd-Elaziz, A. A. & Elshazly, K. M. (2019). Performance enhancement of the photovoltaic cells using Al₂O₃/PCM mixture and/or water-cooling techniques. *Renewable Energy*, 138, 876–890. <https://doi.org/10.1016/j.renene.2019.02.032>.
- Sheikh, Y., Jasim, M., Qasim, M., Qaisieh, A., Hamdan, M. O. & Abed, F. (2024). Enhancing PV solar panel efficiency through integration with a passive multi-layered PCMs cooling system: A numerical study. *International Journal of Thermofluids*, 23. <https://doi.org/10.1016/j.ijft.2024.100748>.
- Singh, V. P., Arya, S. K. & Shankar, A. (2024). Hybrid optimization strategy for water cooling system: enhancement of photovoltaic panels performance. *Energy Harvesting and Systems*, 11(1). <https://doi.org/10.1515/ehs-2023-0091>.
- Waqas, A., Ji, J., Bahadar, A., Xu, L., Zeshan & Modjinou, M. (2019). Thermal management of conventional photovoltaic module using phase change materials—An experimental investigation. *Energy Exploration and Exploitation*, 37(5), 1516–1540. <https://doi.org/10.1177/0144598718795697>.
- Meng, W. W. L., & Lee, L. S. (2021, April). Solar PV cell cooling with a cool water circulation system: Design of a closed-loop cool water re-circulatory system. *Global Scientific Journal*, 9(4). <http://www.globalscientificjournal.com>.
- Wu, S. & Xiong, C. (2014). Passive cooling technology for photovoltaic panels for domestic houses. *International Journal of Low-Carbon Technologies*, 9(2), 118–126. <https://doi.org/10.1093/IJLCT/CTU013>.

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