Protek : Jurnal Ilmiah Teknik Elektro
https://ejournal.unkhair.ac.id/index.php/protk/index
Volume 13. No 1, January 2026
e-ISSN 2527-9572 / p-ISSN 2354-8924

Internet of Things Based Solar Panel Cooling Effectiveness: Automatic and Manual Pump Comparison

Nur Muhammad Abdillah
Department of Electrical Engineering, Faculty of Sains & Technology, Universitas Muhammadiyah Sidoarjo, Jawa Timur, Sidoarjo
nurmuhabdillah121@gmail.com

Izza Anshory*
Department of Electrical Engineering, Faculty of Sains & Technology, Universitas Muhammadiyah Sidoarjo, Jawa Timur, Sidoarjo
Program Studi Profesi Insinyur Universitas Katolik Widya Mandala Surabaya
izzaanshory@umsida.ac.id

Jamaaluddin
Department of Electrical Engineering, Faculty of Sains & Technology, Universitas Muhammadiyah Sidoarjo, Jawa Timur, Sidoarjo

Shazana Dhiya Ayuni
Department of Electrical Engineering, Faculty of Sains & Technology, Universitas Muhammadiyah Sidoarjo, Jawa Timur, Sidoarjo

Andrew Joewono
Program Studi Profesi Insinyur
Universitas Katolik Widya Mandala Surabaya
Jawa Timur, Surabaya

Article history: Received August 10, 2025 | Revised October 20, 2025 | Accepted October 29, 2025

Abstract – **The importance of photovoltaic (PV) systems is emphasized by the increasing demand for renewable energy. However, the increase in temperature on the surface of PV panels greatly affects the performance of PV systems. The impact of IoT-based cooling systems on PV systems is the focus of this study. We applied a comparative experimental design with three configurations: baseline (no cooling), manual (pump activated every 60 minutes for 5 minutes), and automatic (pump activated when the panel temperature 40°C or higher for 5 minutes). The PV panels were equipped with copper pipe cooling, an ESP32 microcontroller, RS485 Modbus communication, and IoT monitoring using Blynk, and were tested outdoors from 08:00 to 16:00. Data collected from the PV (voltage, current, Pmax) was recorded every 5 minutes and analyzed. Our research results show that automatic cooling produces the highest temperature reduction compared to manual cooling. Automatic cooling increases daily PV production by 69.19%, which is equivalent to a 36.05% increase in clean energy. However, the net efficiency of manual cooling is much lower due to fixed-interval pump operation. Therefore, under clear sky conditions, the results show that an automatic cooling system with IoT enables better PV module performance by providing better thermal stabilization. However, considering that this study was only conducted for one day, further research under various weather conditions is needed to prove long-term reliability and consistency.**

Keywords: IoT-based cooling system, photovoltaic performance, solar panel efficiency, automatic pump control, thermal management.

I. Introduction

Increased demand for electricity has become a major and important foundation in human life in the current era. In Indonesia, per capita electricity consumption reached 1,285 kWh in 2023[1]. The achievement of such growth demands urgent actions to reinforce energy sustainability in its source. When it comes to renewable energy potential, Indonesia has a vast amount of solar, hydro, and biomass reserves which are crucial for national energy self-sufficiency[2]. In terms of the before-mentioned renewable energy sources, one is an obvious choice for Indonesia – solar energy. Because the country lies on the equatorial line, it can receive on average ±4.8 kWh/m² per day of incoming solar radiation [3]. With very low operational carbon emissions, this type of energy resource is also valuable to the country because it is abundant, renewable, and environmentally friendly[4]. Therefore, the use of solar technologies like photovoltaic (PV) systems, solar thermal collectors, and integrated energy storage technologies, continues to be the focus of attention for people trying to achieve environmentally clean and sustainable energy[5].

In the literature, the use of solar energy technologies cited various applications in different activities. There are, for instance, solar powered dryers for processed marine products which can achieve and sustain drying temperatures of 48.13 °C during solar radiation can be utilized[6]. Other applications are portable solar systems for providing emergency power supply in post disaster[7]. There is also a solar power system to charge electric bicycles that is efficient and environmentally friendly[8]. The many uses of solar energy in everyday life show how important it is in supporting human activities.

The performance of photovoltaic (PV) solar panels is influenced by environmental factors, particularly temperature. High temperatures have been shown to decrease the efficiency and power output of solar panels.[9],[10]. Previous studies examining PV performance have shown that temperature has a significant impact[11][12][13]. To prevent a decline in electricity production in solar panel (PV) systems, regulating temperature and other factors that can cause overheating is essential. Wind around the panels allows for natural cooling, but most of the time, active cooling is also needed to keep the panel temperature stable[14][15][16].

According to previous studies, solar photovoltaic (PV) modules operate most efficiently at temperatures around 40 °C. When the panel temperature exceeds this optimal level, its performance begins to decline. Research has also shown that PV cooling systems using sprayed water provide better performance compared to those without active cooling. One study, which stabilized the panel temperature at approximately 40 °C, achieved an increase in power output of about 30.19%[17][18][19]. This finding suggests that thermal cooling systems should maintain a set-point temperature of 40 °C. Therefore, various cooling configurations have been developed to sustain such conditions, including water-spray systems with pump-based circulation and Peltier cooling mechanisms[20],[21]. Each system presents distinct advantages and drawbacks depending on its design and surrounding environmental factors..

The development of IoT systems with solar panels (PV) has simplified the process of configuring and monitoring these systems. With IoT connectivity, systems can communicate and send and receive data in real time.Furthermore, remote control of multiple actuators such as valves and pumps has also become possible[22]. Automatic control of brushless DC motors[23], smart logistics[24], livestock monitoring and tracking[25], automated disinfection systems[26], and urban parking management[27] are just a few documented examples of IoT applications in the literature. For solar PV systems, more advanced control and automation in solar PV system cooling thermal management can be achieved with IoT integration. With IoT, automatic cooling pumps are programmed to operate when solar panels reach critical cooling temperatures, thereby improving the thermal management process. IoT also has significant applications beyond solar energy, such as disaster monitoring and early warning systems. For example, community security sensors and mobile applications are integrated to monitor the Lapindo mudflow embankment[28][29].

Regardless, there has yet to be a thorough analysis of IoT-based automated cooling systems compared to manually controlled systems. Manual control, such as Scheduled Operated Pumps, is cheaper and simpler, but may miss most heating peaks and troughs. In contrast, IoT systems save on electricity but are costly to install. This argument is the justification for analysing the advantages and drawbacks, and the reality of the operational context, of fully automated and fully manual systems of cooling.

Several previous studies examined the cooling of solar panels with water, within automated circulation systems, and using Peltier-based modules. A majority of research on this topic is scoped narrowly, focusing only on a single cooling method, and auxiliary power consumption and variation of solar irradiance, causing distortion to the performance assessments, is disregarded. Direct comparative assessments between manual and IoT-based systems under the same outdoor conditions are scarce.

This is the reason the current research aims to address the manual and IoT-based automated cooling systems, with incorporated irradiance and pump energy expenditure values

Due to the scope of the experiment being conducted within a single day, the results are meant to augment the body of work currently available on the topic without attempting to generalise ultra-long term results.

II. METHOD

A. Research Design.

The focus of this research was to ascertain the success of IoT-based solar panel cooling systems through a comparative experiment. Under the same environmental settings, the following three operational modes were observed:

1. Baseline (no cooling): the panel was PV and cooled only by natural convection.
2. Manual IoT pump control: panel pump and solenoid valve turned on for 5 minutes every hour
3. Automatic IoT pump control: the pump and solenoid valve were turned on for 5 minutes whenever the PV surface temperature 40°C or higher as posited by previous works[17].

For each mode to be appropriately compared, every mode was conducted under the same outdoor settings and within the same operational mode (08:00 - 16:00 WIB) on consecutive clear-sky days. The PV surface temperature, voltage, current, output power, net energy balance and other parameters were calculated every 5 minutes and sent to a Google Spreadsheet using the ESP32, knitted within the Blynk IoT Facility, for observation and live evaluation.

B. Environmental Conditions and Irradiance Measurement

The experiment was conducted outdoors for one day, from 08:00 to 16:00, ensuring that the photovoltaic (PV) module remained continuously exposed to natural sunlight during the entire test period.. Environmental factors that affect PV performance metrics such as irradiance, environmental temperature, and sky conditions were continuously measured during the experiment to reduce environmental bias for the subsequent data evaluation. Solar irradiance (W/m²) was measured at 30-minute intervals using a digital solar power meter, while the surface temperature of the panel was continuously monitored in real time through an NTC sensor connected to an ESP32 microcontroller.. During all the tests, sky conditions (clear, partly cloudy, or cloudy) were observed and recorded to ensure uniform exposure between all test modes. These later supported data showing solar intensity, panel surface temperature, and maximum power (Pmax) to minimise difference in performance cooling effect while attributing variation to differences in irradiance.

Additionally, the impacts of wind speed and humidity were omitted from the experiment's frames of reference; thus, the omitted data stands as a limitation for this single-day field experiment.

C. Research Tools and Materials.

The experiment setup included a photovoltaic panel of 50 Wp, a DC water pump controllable via IoT, an ESP32 microcontroller, an NTC thermistor for measuring PV surface temperature, a charge controller, MODBUS RS485–TTL module, a relay module, a solenoid valve, and copper pipes mounted to the back side of the PV panel which acted as a coolant. The coolant was stored and distributed by means of a water tank and circulation pipes. Data acquisition and visualisation were performed through the Blynk IoT platform and Google Spreadsheet.

D. System Design.

The RS485 TTL and the NTC sensor were used to obtain photovoltaic parameters and retrieve data at the panel's surface temperature respectively. In both cases, the ESP32 served as both the central controller and the source to retrieve the data. The operating mode determined the operating parameters to which the ESP32 activated the relay. In automatic mode, the pump, as well as the solenoid valve, would be activated when the panels exceeded the temperature 40°C or higher, and in manual mode, the pump would receive 5 minutes of activation every 60 minutes.

The overall architecture of the system is illustrated in Fig. 1.

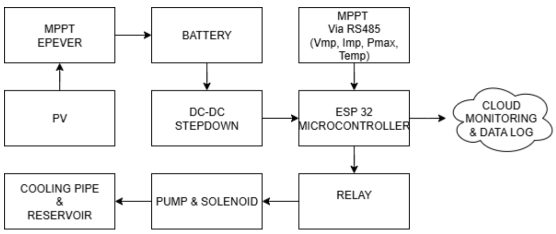

Figure 1. Block diagram of the IoT-based PV cooling system

Referring to Fig 1, the ESP32 receives Vmp, Imp, Pmax, and temperature data from the MPPT over the RS485 module while the NTC records the instantaneous surface temperature. The ESP32 controls the relay to activate the pump and solenoid valve while simultaneously sending designed data to the cloud. Upper layer monitoring is processed and sent to the platform for data logging and rest analysis.

The detailed electrical configuration is presented in Fig. 2.

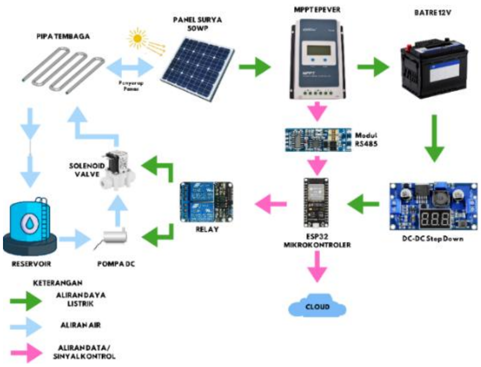

Figure 2. Electrical circuit design

The interactions between components of the system shown in Fig. 2 is illustrated using green arrows for power flow, blue arrows for water circulation, and purple arrows for data and control signals. This configuration maintains the system's neuromorphic and concurrent sensing, acting, and communicating capabilities.

The physical prototype of the cooling mechanism is shown in Fig. 3.

Figure 3. 3D prototype design of copper pipe cooling layout on PV panel

As illustrated in Fig. 3, shows that the copper pipe is positioned in a counterflow arrangement to maximise the cooling of the PV surface and capture the heat on the PV surface. This configuration provides satisfactory cooling performance in both manual and automatic operation modes.

E. Research Procedure.

The experimental development is implemented through the use of a PV panel with a cooling system using copper pipe and the installation of ESP32 with an NTC sensor, RS-485 module, relay, pump, and solenoid valve. During the tests, the following modes were activated: baseline, manual, and automatic. The results were the registration of PV parameters and the study of panel temperature, which were sent to Google Spreadsheet every five minutes. The left side is automatic mode, where the ESP32 turns on the pump and solenoid valve based on temperature (if the temperature 40°C or higher), which will run for 5 minutes. On the right side is manual mode, where the pump and solenoid valve will run for 5 minutes every hour regardless of the panel temperature.

F. Mathematical Formulation.

The data from the test results can be analyzed using the following formulas

1. PV power at each interval

$$P_{mp}(t) = V_{mp}(t)\ x\ I_{mp}(t) \qquad (1)$$

2. PV energy per interval

$$E_{pv}(t) = P_{mp}(t)\ x\ \Delta t_h \qquad (2)$$

With $\Delta t_h = \frac{300}{3600} = 0{,}08333$ hour

3. Pump power

$$P_{pump}(t) = V_{pump}(t)\ x\ I_{pump}(t) \qquad (3)$$

4. Pump energy per interval

$$E_{pump}(t) = P_{pump}(t)\ x\ \Delta t_h \qquad (4)$$

5. Daily PV and pump energy

$$E_{pv,day} = \sum_t E_{pv}(t) \qquad (5)$$

$$E_{pump,day} = \sum_t E_{pump}(t) \qquad (6)$$

6. Net daily energy

$$E_{net,day} = E_{pv,day} - E_{pump,day} \qquad (7)$$

7. Relative gain compared to baseline

$$\%Gain = \frac{E_{net,day}^{(mode)} - E_{net,day}^{(baseline)}}{E_{net,day}^{(baseline)}}\ x\ 100\% \qquad (8)$$

8. Average temperature reduction

$$\Delta T = T_{panel}^{(baseline)} - T_{panel}^{(mode)} \qquad (9)$$

III. Results and Discussion

This study was conducted in three modes: baseline (without cooling), manual, and automatic. Data was recorded every five minutes and combined into a 30-minute average to facilitate analysis. The data collected included PV surface temperature, voltage (Vmp), current (Imp), power (Pmax), and pump status.

Table 1 below shows the results of solar radiation intensity during testing. The results show that solar radiation intensity always increases gradually and decreases gradually in the afternoon. This data is used as a reference to distinguish the effect of radiation intensity and panel temperature on PV power output, so that changes in Pmax are not misinterpreted as solely the result of cooling.

Table 1 Irradiance & Sky Condition Data

Time	Irradiance (W/M^2)	Sky Condition
08:00-08:30	850	Partly Cloudy
08:30-09:00	865	Partly Cloudy
09:00-09:30	940	Clear
09:30-10:00	975	Very Clear
10:00-10:30	890	Partly Cloudy
10:30-11:00	905	Mostly Clear
11:00-11:30	892	Partly Cloudy
11:30-12:00	915	Mostly Clear
12:00-12:30	895	Partly Cloudy
12:30-13:00	902	Mostly Clear
13:00-13:30	925	Mostly Clear
13:30-14:00	720	Cloudy
14:00-14:30	930	Clear
14:30-15:00	935	Clear
15:00-15:30	820	Partly Cloudy
15:30-16:00	760	Cloudy

Table 1 indicates that during the morning hours, solar irradiance was high, then it relatively increased to peak in the midday. Thereafter, the irradiance decreased in the afternoon. This demonstrates a clear daily pattern of solar radiation. The maximum values of irradiance observed were from 09:30 to 14:30 when the sky was also clear except at times when it was partly cloudy. The lowest irradiance values were recorded during the heavily cloudy periods. All variation in solar intensity has a direct impact on the electrical output of the PV panel in all four cooling scenarios. It is, therefore, important to refer to the irradiance pattern as shown in table 1 to assess the relationship between the panel temperature and Pmax in the three. To cancel out the impact of irradiance deviations, all weather-dependent tests were conducted on the analogous day, boilerplate irradiance levels of between 09:00 and 14:30, as weather remained relatively consistent during these hours. Thus, discrepancies in power and temperature discussed can be entirely imputed to thermal efficiency and not irradiance alteration. Sky conditions were also noted while taking measurements to confirm that similar conditions were constant in all aspects. Table 2 shows the PV performance without cooling.

Table 2 PV performance in baseline mode

Time	Temp (C)	Vmp (V)	Imp (A)	Pmax (W)	Pump Status
08:00-08:30	37.90	16.96	1.03	17.52	-
08:30-09:00	39.46	16.75	1.08	18.12	-
09:00-09:30	38.59	16.60	1.25	20.69	-
09:30-10:00	37.74	16.57	1.23	20.35	-
10:00-10:30	41.75	16.38	1.01	16.58	-
10:30-11:00	53.04	15.75	1.08	16.99	-
11:00-11:30	54.57	20.05	1.29	25.81	-
11:30-12:00	55.32	19.84	1.38	27.45	-
12:00-12:30	54.95	18.69	1.36	25.35	-
12:30-13:00	54.54	14.19	1.27	17.97	-
13:00-13:30	54.90	16.58	1.15	19.09	-
13:30-14:00	55.12	13.70	1.01	13.89	-
14:00-14:30	46.71	12.92	0.85	11.04	-
14:30-15:00	38.54	12.87	0.63	8.17	-
15:00-15:30	37.90	12.60	0.42	5.31	-
15:30-16:00	37.51	12.50	0.58	7.30	-

In baseline mode, the PV temperature increases during the day to exceed 55 °C. This increase in temperature results in a decrease in Pmax output. Since there is no cooling, this results in the lowest efficiency among all modes.

Table 3 shows the PV performance results when the pump is scheduled to operate for five minutes every hour.

Table 3 PV performance in manual cooling mode

Time	Temp (C)	Vmp (V)	Imp (A)	Pmax (W)	Pump Status
08:00-08:30	36.87	17.05	1.41	23.99	ON
08:30-09:00	40.25	16.80	1.51	25.29	OFF
09:00-09:30	38.43	16.67	1.71	28.56	ON
09:30-10:00	38.81	16.98	1.67	28.34	OFF
10:00-10:30	39.87	16.83	1.73	29.10	ON
10:30-11:00	42.01	16.66	1.74	29.00	OFF
11:00-11:30	39.55	16.75	1.85	30.96	ON
11:30-12:00	42.42	16.77	1.72	28.77	OFF
12:00-12:30	40.54	16.94	1.62	27.42	ON
12:30-13:00	40.43	17.01	1.63	27.76	OFF
13:00-13:30	40.04	17.09	1.60	27.36	ON
13:30-14:00	41.46	17.19	1.36	23.36	OFF
14:00-14:30	40.55	17.19	1.14	19.51	ON
14:30-15:00	39.46	17.67	0.99	17.41	OFF
15:00-15:30	36.32	16.42	0.16	2.56	ON
15:30-16:00	34.73	16.19	0.11	1.86	OFF

In manual mode, the pump successfully lowers the surface temperature compared to the baseline, with the average value remaining below 45 °C. As a result, Pmax output increases during the day. However, because the pump operates on a fixed schedule, energy is sometimes wasted.

Table 4 shows the PV performance results when the pump operates for 5 minutes when the temperature exceeds 40 °C.

Table 4 PV performance in automatic cooling mode

Time	Temp (C)	Vmp (V)	Imp (A)	Pmax (W)	Pump Status
08:00-08:30	38.02	16.93	1.46	24.75	OFF
08:30-09:00	35.65	16.81	1.77	29.70	ON 2X
09:00-09:30	35.64	16.63	2.03	33.77	ON 1X
09:30-10:00	35.88	16.56	2.11	34.98	ON 2X
10:00-10:30	36.34	16.49	2.10	34.63	ON 3X
10:30-11:00	36.68	16.61	1.98	32.96	ON 2X
11:00-11:30	37.51	16.71	1.86	31.13	ON 2X
11:30-12:00	38.09	16.99	1.90	32.20	ON 2X
12:00-12:30	37.72	19.92	1.90	32.16	ON 1X
12:30-13:00	37.83	16.79	1.87	31.41	ON 2X
13:00-13:30	39.26	17.09	1.73	29.53	OFF
13:30-14:00	39.14	17.21	1.54	26.53	OFF
14:00-14:30	38.23	17.21	1.56	26.88	ON 1X
14:30-15:00	38.48	16.80	1.55	31.57	OFF
15:00-15:30	37.92	17.26	1.46	25.18	OFF
15:30-16:00	34.76	15.89	0.13	2.13	OFF

The automatic mode showed the most effective temperature control, with average panel temperatures maintained around 37–39 °C. Pmax consistently reached higher values than both baseline and manual modes, especially during midday. Even though the pump activated multiple times per interval, energy use was more efficient as activation was based on real-time thermal conditions.

The average temperature reduction was calculated using equation (8)

Where $T_{panel}^{(baseline)}$ is the average PV surface temperature in baseline mode, and $T_{panel}^{(mode)}$ is the average temperature under manual or automatic cooling operation. The results are presented in Table 5.

Table 5 Average temperature reduction in each mode

Mode	Avg Temp (°C)	ΔTavg vs Baseline (°C)
Baseline	46.16	-
Manual	39.48	6.68
Automatic	37.32	8.84

The results confirm that manual cooling reduced panel temperature by 6.68 °C, while automatic cooling achieved an even greater reduction of 8.84 °C. This highlights the advantage of adaptive cooling control.

Using equations (1)–(2), the daily PV energy output was calculated.

Table 6 PV energy output comparison

Mode	Daily PV Energy (Wh)	Relative Gain vs Baseline (%)
Baseline	135.81	-
Manual	185.62	36.68
Automatic	229.77	69.19

Manual cooling increased daily energy by 36.68% relative to baseline, while automatic cooling achieved the highest improvement at 69.19%.

Using equations (3)–(7), the pump consumption and net daily PV energy were determined.

Table 7 Pump consumption and net PV energy

Mode	Pump Energy (Wh)	Net PV Energy (Wh)	Relative Gain vs Baseline (%)
Baseline	-	135.81	-
Manual	17.50	168.12	23.79
Automatic	45	184.78	36.05

Automatic operation uses more energy from the pump than manual settings, but still provides the greatest clean energy benefits thanks to much more effective temperature control. The lowest net output occurs in basic mode. As a result, the smallest increase in net output occurs in manual cooling, as expected.

For this article, the energy collected minus the energy used to pump water defines energy efficiency. Automatic mode still uses more pump energy, but is considered more efficient in terms of clean energy output. To visualize the effect of the cooling strategies, the results were plotted in separate graphs for PV surface temperature and maximum power output.

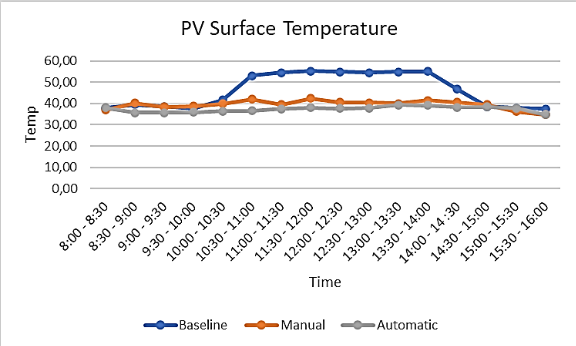

Figure 4 PV Surface Temperature

As shown in Figure 4, the basic mode displays a temperature increase exceeding 55 °C at midday. Manual cooling lowers the temperature curve by several degrees, while automatic cooling consistently maintains the lowest temperature. This proves that the automatic mode provides more effective temperature control during the test period.

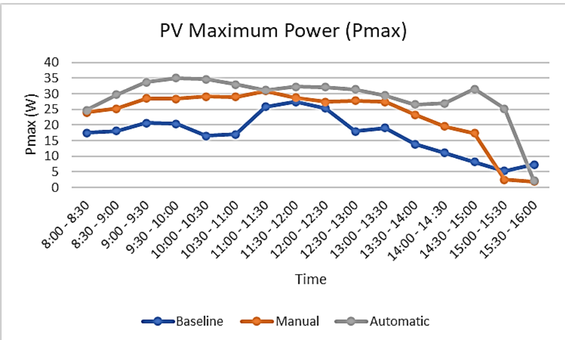

Figure 5 PV Maximum Power (Pmax)

Figure 5 illustrates the changes in Pmax over the day. The panel in the baseline mode demonstrated decreased output during hours of high temperatures. The manual cooling provided some improvement during the same period. Automatic cooling always demonstrated the highest panel output, especially around midday. It indicates its superior ability to stabilize the panel efficiency under variable irradiation and temperatures.

The Pmax pattern generally followed the irradiance one. The automatic cooling implementation still yielded higher output within similar intervals under the same irradiance conditions. This indicates that temperature control is more important in our research than irradiance stabilization.

In real-life implementation, some technical features should be mentioned. Continuous water cycling may result in the appearance of minerals on the panel's surface if non-pure water is used. In the long run, it can reduce light transmission slightly. The copper pipes involved should be monitored for the lack of oxygen in the water. Dust and the cooling system's weight also can add some load to the PV structure; however, these aspects were not studied as they are better evaluated in longer terms and should be studied in the future as part of the next phases of our project.

IV. Conclusion

Under the clear-sky environment, this research underscored the effectiveness of IoT-based cooling techniques on photovoltaic (PV) performance compared to the baseline and manual modes. The automatic pump mode is capable of decreasing the average panel temperature by 8.84 °C, which, in turn, leads to the enhanced daily energy yield in PVs by 69.19% along with the net energy gain of 36.05% with respect to the baseline. The manual cooling system also yields an increase in the PV daily energy yield, though the net efficiency is lower due to the fixed-interval of the system.bIoT with photovoltaic (PV) systems is aided by efficient algorithms which increase the net energy gain of the system on controlled parameters through responsive thermal IoT systems and log of energy yield on a daily scale. Even though the current observations were limited to a one-day experiment, other multi-day solar data sets and adverse weather parameters would set the system for environmental adaptability, long-term reliability, and performance consistency.

REFERENCES

[1] A. C. Adi, "Konsumsi Listrik Masyarakat Meningkat, Tahun 2023 Capai 1.285 kWh/Kapita, 2024." Accessed: May 11, 2025. [Online]. Available: https://www.esdm.go.id/id/media-center/arsip-berita/konsumsi-listrik-masyarakat-meningkat-tahun-2023-capai-1285-kwh-kapita

[2] "SEBAIKNYA KONSUMEN TAHU TENTANG PLTS & Biodiesel," Modul Pembelajaran. [Online]. Available: https://energiterbarukan.org/assets/2020/10/BUKU-PLTS-DAN-BIODISEL.pdf

[3] F. Afif and A. Martin, "Tinjauan Potensi dan Kebijakan Energi Surya di Indonesia," *J. Engine Energi, Manufaktur, dan Mater.*, vol. 6, no. 1, p. 43, 2022, doi: 10.30588/jeemm.v6i1.997.

[4] V. Dwisari, S. Sudarti, and Y. Yushardi, "Pemanfaatan Energi Matahari: Masa Depan Energi Terbarukan," *Opt. J. Pendidik. Fis.*, vol. 7, no. 2, pp. 376–384, 2023, doi: 10.37478/optika.v7i2.3322.

[5] I. Anshory *et al.*, "Monitoring solar heat intensity of dual axis solar tracker control system: New approach," *Case Stud. Therm. Eng.*, vol. 53, no. October 2023, p. 103791, 2024, doi: 10.1016/j.csite.2023.103791.

[6] J. Jamaaluddin *et al.*, "Heat Transfer Management of Solar Power Plant for Dryer," *Int. J. Eng. Appl.*, vol. 12, no. 3, p. 195, May 2024, doi: 10.15866/irea.v12i3.23959.

[7] J. Jamaaluddin, I. Anshory, S. B. Sartika, Khoiri, and Mardiyono, "Utilizing Solar Power for Communication and Illumination in Disaster Zones," *Acad. Open*, vol. 8, no. 2, Aug. 2023, doi: 10.21070/acopen.8.2023.7236.

[8] M. R. Pratama, J. Jamaaluddin, and I. Sulistiyowati, "Electric Bicycle Battery Charging System Design Using Solar Panel," *JEEE-U (Journal Electr. Electron. Eng.*, vol. 8, no. 2, pp. 71–81, 2024, doi: 10.21070/jeeeu.v8i2.1698.

[9] N. Atikah, B. Pramono Jati, and D. Nugroho, "Analisis Pengaruh Suhu Terhadap Daya Output pada Panel Surya Monocrystalline dan Polycrystalline 50 Wp," *Cyclotron*, vol. 7, no. 02, pp. 18–25, 2024, doi: 10.30651/cl.v7i02.21822.

[10] A. F. Aditya and A. Ulinuha, "Analysis of Photovoltaic Panel Performance Integrated with the Grid in a Load-Sharing Scheme," *ELKHA*, vol. 17, no. 1, pp. 53–60, Apr. 2025, doi: 10.26418/elkha.v17i1.91191.

[11] J. T. Mesin, F. Sains, and U. B. Belitung, "PENGARUH PENDINGINAN PANEL SURYA TERHADAP EFISIENSI

DAYA KELUARAN," vol. 10, no. 1, pp. 36–40, 2024.

[12] V. F. Abast, H. J. R. Sumarauw, J. C. Kewas, F. Teknik, P. Studi, and T. Mesin, "ANALISA SUHU PERMUKAAN TERHADAP DAYA OUTPUT SOLAR CELL 10 WP TIPE MONOCRYSTALLINE Viktor," vol. 3, no. 2, pp. 1–8, 2023.

[13] R. Y. Prasetiya, S. A. Adilla, M. F. K. Farid, E. A. Hakim, and D. Suhardi, "Performance Analysis of the 1 MW Rooftop Solar Power Generation System at the Karawang," *JEEE-U (Journal Electr. Electron. Eng.*, vol. 8, no. 2, pp. 60–70, 2024, doi: 10.21070/jeeeu.v8i2.1685.

[14] A. Husai Siregar and P. Harahap, "Analisis Pengaruh Suhu dan Angin Terhadap Daya dan Efisiensi Panel Surya 100 Wp," *J. Tek. Elektro dan Komput.*, vol. 13, no. 02, pp. 97–102, Aug. 2024, doi: 10.35793/jtek.v13i02.55319.

[15] J. Harie Satiyadi, R. Muhamad Hudan, and A. Asrori, "Analisis Pengaruh Suhu Panel Surya Terhadap Output Panel Performance," *J. Mech. Eng.*, vol. 1, no. 1, pp. 42–51, 2024, doi: 10.47134/jme.v1i1.2189.

[16] Suwarti, Wahyono, and B. Prasetiyo, "Analisis Pengaruh Intensitas Matahari, Suhu Permukaan & Sudut Pengarah Terhadap Kinerja Panel Surya," *Eksergi*, vol. 14, no. 3, p. 78, 2019, doi: 10.32497/eksergi.v14i3.1373.

[17] E. P. LAKSANA, O. SANJAYA, S. SUJONO, S. BROTO, and N. FATH, "Sistem Pendinginan Panel Surya dengan Metode Penyemprotan Air dan Pengontrolan Suhu Air menggunakan Peltier," *ELKOMIKA J. Tek. Energi Elektr. Tek. Telekomun. Tek. Elektron.*, vol. 10, no. 3, p. 652, 2022, doi: 10.26760/elkomika.v10i3.652.

[18] Z. R. Tahir *et al.*, "Effect of Temperature and Wind Speed on Efficiency of Five Photovoltaic Module Technologies for Different Climatic Zones," *Sustain.*, vol. 14, no. 23, 2022, doi: 10.3390/su142315810.

[19] F. Shaik, S. S. Lingala, and P. Veeraboina, "Effect of various parameters on the performance of solar PV power plant: a review and the experimental study," *Sustain. Energy Res.*, vol. 10, no. 1, 2023, doi: 10.1186/s40807-023-00076-x.

[20] R. Pido, "ANALISA PENGARUH KENAIKAN TEMPERATUR PERMUKAAN SOLAR CELL TERHADAP DAYA OUTPUT," *Gorontalo J. Infrastruct. Sci. Eng.*, vol. 2, no. 2, p. 24, Oct. 2019, doi: 10.32662/gojise.v2i2.683.

[21] N. M. Janna and D. A. Widodo, "Analisis Karakteristik Modul Panel Surya Dengan Sistem Pendingin Air," *J. Fokus Elektroda Energi List. Telekomun. Komputer, Elektron. dan Kendali)*, vol. 6, no. 1, p. 37, 2021, doi: 10.33772/jfe.v6i1.16200.

[22] Y. M. Al-Sharo, K. Al Smadi, T. Al Smadi, and Y. K. N., "Optimization of Stable Energy PV Systems Using the Internet of Things (IoT)," vol. 31, no. 1, pp. 127–137, 2024, doi: http://doi.org/10.25130/tjes.31.1.11.

[23] I. Anshory, A. Wisaksono, J. Jamaaluddin, and A. Fudholi, "Implementation of ARM STM32F4 microcontroller for speed control of BLDC motor based on bat algorithm," *Int. J. Power Electron. Drive Syst.*, vol. 15, no. 1, pp. 127–135, 2024, doi: 10.11591/ijpeds.v15.i1.pp127-135.

[24] I. Sulistiyowati, A. I. Muzaqi, M. S. Maulana, M. T. Alimova, and Supardi, "Revolutionizing package delivery with IoT-based smart boxes: Solving the Dilemma of missed deliveries," 2024, p. 020006. doi: 10.1063/5.0220240.

[25] S. Syahrorini, A. Rifai, D. H. R. Saputra, and A. Ahfas, "Design Smart Chicken Cage Based On Internet Of Things," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 519, p. 012014, Jul. 2020, doi: 10.1088/1755-1315/519/1/012014.

[26] A. Ahfas, M. B. Ulum, D. H. R. Saputra, and S. Syahrorini, "Automatic Spray Desinfectant Chicken with Android Based on Arduino Uno," *IOP Conf. Ser. Earth Environ. Sci.*, vol. 519, no. 1, 2020, doi: 10.1088/1755-1315/519/1/012013.

[27] A. Wisaksono and C. Aswar Ragil, "Design and Development of Parking Motor Parking Information System at Muhammadiyah University , Sidoarjo Design and Development of Parking Motor Parking Information System at Muhammadiyah University , Sidoarjo", doi: 10.1088/1757-899X/874/1/012015.

[28] S. D. Ayuni, S. Syahrorini, and J. Jamaaluddin, "Lapindo Embankment Security Monitoring System Based on IoT," *Elinvo (Electronics, Informatics, Vocat. Educ.*, vol. 6, no. 1, pp. 40–48, 2021, doi: 10.21831/elinvo.v6i1.40429.

[29] S. D. Ayuni, S. Syahrorinni, and J. Jamaaluddin, "Sosialisasi Aplikasi Monitoring Keamanan Tanggul Lapindo via Smartphone di Desa Gempolsari," *J. Pengabdi. Masy. Progresif Humanis Brainstorming*, vol. 5, no. 1, pp. 154–161, 2022, doi: 10.30591/japhb.v5i1.2717.