MOTIVECTION
Journal of Mechanical Electrical and Industrial Engineering

Volume: 7, Number: 1, 2025
ISSN: 2655 – 7215 [printed]; 2685-2098 [online]
DOI: https://doi.org/10.46574/motivection.v7i1.407

Thermal Cooling of Solar Panels: Effectiveness of Copper Pipes in Temperature Regulation

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ABSTRACT

This study evaluates the effectiveness of a thermal cooling system utilizing copper pipes in regulating solar panel temperature and enhancing energy efficiency. The system incorporates water-fed copper pipes with an automatic valve mechanism, which controls water flow based on real-time temperature measurements. Experiments were conducted at Universitas Muhammadiyah Sidoarjo using two 100 Wp solar panels, where key parameters such as voltage, current, power output, and surface temperature were monitored. The results demonstrate that the cooling system effectively lowers panel temperature, leading to significant improvements in voltage and power generation. The cooled solar panel achieved a maximum efficiency of 43.7%, compared to only 24.07% without cooling. Additionally, the cooling system stabilized maximum power voltage (VMP) and maximum power output (PMAX), preventing performance degradation due to excessive heat accumulation. These findings confirm that integrating a copper pipe thermal cooling system enhances solar panel efficiency, providing a viable solution for improving photovoltaic energy conversion and ensuring long-term operational stability.

Keywords
Solar Panel, Cooling System, Copper Pipe, Automatic Valve

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Submitted : December 16, 2024. Accepted : January 20, 2025. Published : February 26, 2025

INTRODUCTION

Indonesia is a tropical nation situated between 6° N and 11° S latitude and 95° E and 141° E longitude, in proximity to the Equator. The nation possesses considerable solar energy potential, estimated at around 4.8 kWh/m^2 daily [1]. As an archipelagic nation, numerous isolated settlements are devoid of energy connection. The Ministry of Energy and Mineral Resources (ESDM) reports that 12,669 villages in Indonesia lack power connections, with 2,519 of these villages entirely devoid of illumination. This problem primarily arises from the constraints of the national electricity grid (PLN) in accessing outlying regions and the inadequate exploitation of the nation's plentiful solar energy resources. Solar power plants (PLTS), recognized for their versatility and user-friendly technology, present a feasible alternative for electricity generation [2][3].

Solar panels are a crucial technology for transforming sunlight into sustainable electrical energy; yet, their efficacy is considerably affected by operational temperature [4]. The ideal temperature range for solar panels is 46°C to 49°C, during which they attain an efficiency of 6.1% to 6.7% [5]. Nevertheless, as temperature rises, the efficiency of energy conversion diminishes. Research demonstrates that lowering panel temperature to 42°C can enhance efficiency to 7.0–7.8% [6][7]. Consequently, an efficient thermal cooling system is crucial for sustaining appropriate operating temperatures and enhancing overall system performance.

One promising cooling method involves the use of copper pipes (Figure 1) as a thermal medium. Copper has high thermal conductivity, allowing it to efficiently absorb and dissipate heat. This property enables copper pipes to lower solar panel temperatures, keeping them within optimal operational limits. Thus, implementing a cooling system utilizing copper pipes has the potential to enhance solar panel energy efficiency.

Figure 1. Copper Pipe

This study aims to evaluate the effectiveness of water-cooled copper pipes in reducing solar panel temperatures to ensure optimal performance. The evaluation is conducted by comparing the power output and voltage of solar panels equipped with a cooling system to those without cooling. This study's principal innovation is the incorporation of an automated valve at both the intake and outflow of the copper pipes. This valve modulates water flow according to the measured temperature, enabling the cooling system to function efficiently and effectively. This study examines the utilization of copper pipes and their effect on improving solar panel efficiency, building upon prior research that investigated diverse solar panel cooling techniques.

Solar Panel

A solar panel is a system that converts solar energy into electricity using photovoltaic technology [8]. This process occurs when photons (light particles) transfer energy to solar cells, which contain both positive and negative charges, generating an electric field that produces an electric current [9]. The electricity produced is in the form of direct current (DC), which can be used directly for electrical applications or stored in batteries for future use. To achieve the desired power output, solar cells are connected in series and parallel through a network collector busbar [10][11]. The intensity of solar radiation significantly affects solar panel power generation, while high temperatures and weather fluctuations can reduce efficiency. Additionally, wind speed plays a crucial role in cooling the panel surface, as higher wind speeds enhance heat dissipation, helping maintain optimal operating temperatures [12]. Solar panels function by arranging solar cells in an optimized configuration to maximize sunlight absorption. Each solar cell contains photovoltaic elements that directly convert light (photo) into electrical energy (voltaic) [13].

Cooling System

A cooling system is a device that controls an object's temperature by moving heat from the object to the ambient air. Cooling transpires when a temperature gradient exists between two places, facilitating the transfer of heat from the hotter part to the cooler one. Common cooling strategies encompass air-blown cooling, water-flow cooling, heatsink-based cooling, and hybrid cooling systems that amalgamate various cooling methods [14][15].

Solar cell surfaces cooled by water maintain lower temperatures, as heat is transferred from the cells to the circulating water through pipes. In contrast, solar cell surfaces without a cooling system absorb direct sunlight, leading to higher surface temperatures [16]. A cooling system effectively reduces solar panel temperature, thereby enhancing power output. Lowering solar panel temperature positively impacts the open-circuit voltage, ultimately improving overall power generation efficiency [17].

Solar Panel Effectiveness

The effectiveness of a solar panel is determined by its ability to convert sunlight into electrical power. Climatic variations significantly impact solar energy production, as solar panels absorb more energy under clear skies than in cloudy or overcast conditions. Several factors influence solar panel efficiency, including solar radiation intensity, wind speed, and environmental conditions [18]. Increased solar radiation intensity allows solar panels to absorb greater energy, thereby enhancing power generation efficiency. Moreover, wind velocity is essential in cooling solar panels, averting overheating that may impair performance. Moreover, environmental variables such air temperature, humidity, and precipitation influence the total efficacy of solar panels [19].

The equation for determining solar panel efficiency is as Equation 1:

$$n = \frac{P_{out}}{P_{in}} x\ 100\% \tag{1}$$

Using this calculation, the efficiency of a solar panel can be determined. Here, P_out represents the average maximum power P_max, while P_in refers to the input power supplied to the solar panel.

Literature Review

Investigations into solar panel cooling systems have examined the utilization of water coolant, mineral water, and seawater as cooling mediums. A monocrystalline 20W solar panel served as the test subject, and an experimental method was utilized to compare temperature and voltage measurements. The results indicated that the highest efficiency levels attained were 15.41% and 14.74%. The principal benefit of this work is that heated water can be efficiently employed as a cooling mechanism, demonstrated by the decrease in surface temperature. Nevertheless, a significant disadvantage is the supplementary expense linked to the utilization of water coolant [20].

A separate study investigated solar panel cooling using copper pipes. The methodology followed an experimental approach, beginning with the design and fabrication of a prototype, followed by performance evaluation. The evaluated parameters included solar radiation, temperature, and panel voltage. The results indicated a gradual increase in temperature over time. The maximum average voltage recorded with cooling was 17.2V, significantly higher than the 15.6V measured without cooling. The main advantage of this research is the potential reuse of warm water for daily activities, along with a notable improvement in voltage output. However, a key limitation is the need for a systematic design to ensure uniform water flow throughout the copper pipes [21].

Innovation

The solution proposed in this study integrates automatic valve faucet technology into both the input and output sections of the copper pipe cooling system. This approach enables automatic water inflow and outflow, eliminating the need for manual faucet operation. The input valve is energized by voltage, resulting in its opening and permitting water to enter the copper pipe. The output valve functions according to temperature measurements from the Maxx6675 sensor. When the temperature surpasses the established threshold for solar panel cooling, the output valve activates, facilitating water release. If the temperature stays below the designated threshold, the water is routed to the primary storage tank for reutilization. Although considerable study has been conducted on solar panel cooling systems, no prior studies have integrated automatic valve faucet technology. This study presents a novel automated system that improves efficiency and user convenience by minimizing manual intervention and optimizing water management in the cooling process.

METHOD

This study employs a quantitative research methodology to ensure accurate and measurable results. This approach is particularly useful for evaluating the performance of the proposed cooling system and determining its applicability in similar climatic conditions. The study aims to assess the impact of the cooling system on solar panel efficiency through quantitative measurements conducted in a controlled and replicable manner.

The experimental study, as shown in Figure 2, was performed at Universitas Muhammadiyah Sidoarjo from 11:00 AM to 2:00 PM, guaranteeing sufficient solar exposure. Data collection occurred over two distinct days, each allocated to a specific experimental condition: one day for assessing the photovoltaic (PV) panel without a cooling system, and another for examining the panel with the cooling system installed. Measurements were documented every 10 minutes throughout each testing session to guarantee data consistency and reduce variability. This study analyzes critical characteristics, such as maximum voltage (PMAX), maximum current (IMP), surface temperatures of the upper and lower sides of the solar panel, intake and exit water temperatures, and maximum power output. Moreover, external environmental conditions, including ambient temperature, solar radiation intensity, and humidity levels, were observed, as these variables directly affect the efficacy of the cooling system.

Figure 2. Data acquisition with Smart Sensors

A set of precise measuring instruments was employed to ensure reliable data acquisition. An AvoMeter was used to measure voltage and current, while a Thermal Imaging Camera captured surface temperature fluctuations of the solar panel. A Solar Panel Multimeter was utilized to assess power output. The solar panel's surface temperature was accurately measured using a Thermal Imaging Camera, which collected thermal data from both the upper and lower sides of the panel. Simultaneously, voltage, current, and power output were recorded using the Solar Panel Multimeter, ensuring precision in performance evaluation.

Subsequent to data collection, the results were methodically evaluated to discern discrepancies in solar panel performance under cooling and non-cooling situations. The results were illustrated via graphical representations and comparative studies, showcasing the cooling system's efficacy in improving solar panel efficiency.

Figure 3 consists of two primary components: the controller circuit and the solar panel circuit. The solar panel circuit includes a 100 Wp solar panel, a solar charge controller (SCC), and a 12V 50Ah battery. These components work together to capture solar energy, regulate power distribution, and store energy, ensuring continuous operation. The controller circuit comprises an Arduino microcontroller, a MAX6675 temperature sensor, a 5V step-down converter, a solenoid valve, and an I2C LCD display. The step-down converter is linked to the microcontroller, regulating the battery voltage to a level sufficient for the Arduino's functionality. The MAX6675 sensor, connected to the Arduino, operates as a temperature sensor for monitoring incoming and outgoing water. The temperature data are presented on the I2C LCD panel for real-time monitoring.

Figure 3. Copper Pipe Design on the Solar Panel

The solenoid valve, located at the input and output parts of the piping system, modulates water flow according to temperature measurements. Upon detecting a temperature over the established threshold, the MAX6675 sensor prompts the Arduino to engage the solenoid valve, facilitating water circulation to efficiently cool the solar panel. Figure 4 presents a comprehensive illustration of this system architecture.

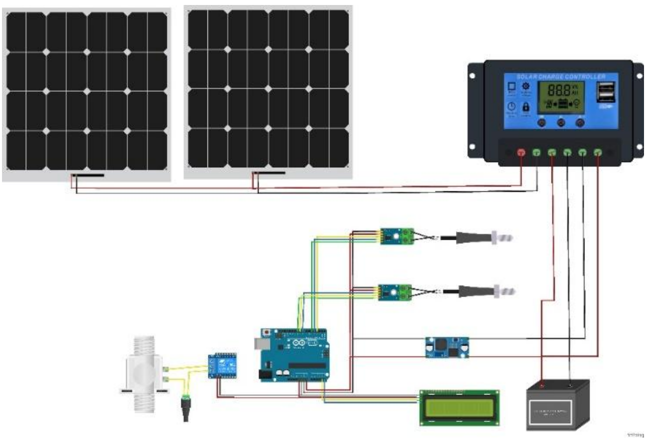

Figure 4. Design of the Copper Pipe Cooling System

Flowchart of the Cooling System Process

The cooling process begins with water entering the input solenoid valve. When voltage is applied, the solenoid valve activates, allowing water to flow into the copper piping system. As the water circulates through the pipes, it absorbs heat from the solar panel, thereby reducing the panel's surface temperature. The system continuously monitors temperature using the MAX6675 sensor. When the sensor detects a temperature of 45°C or higher, the output solenoid valve opens, allowing the expulsion of hot water from the system. If the temperature remains below the threshold, the output valve remains closed, and the water is redirected to the main storage tank for recirculation.

This automated control system ensures efficient temperature regulation, improving the solar panel's operational performance while minimizing water consumption. Figure 5 provides a detailed visualization of the cooling system process.

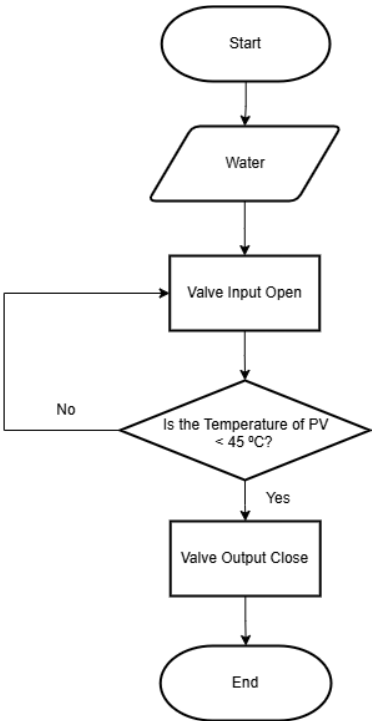

Figure 5. Flowchart Diagram

RESULT AND DISCUSSION

The measurement data were acquired by documenting VMP (Maximum Power Voltage), IMP (Maximum Power Current), PMAX (Maximum Power Output), the surface temperatures of both the upper and lower sides of the solar panel, as well as the input and output water temperatures. The incorporation of flowing water in the copper pipe cooling system resulted in significant fluctuations in temperature and power output, as illustrated in Table 1.

These fluctuations result from the continuous movement of the sun throughout the day, affecting solar radiation intensity and temperature distribution on the panel surface. This dynamic condition highlights the importance of an efficient cooling system to maintain the solar panel's optimal operating temperature and improve overall efficiency.

Table 1 presents the measurement results from a single experimental trial. The highest maximum power output (PMAX) recorded was 96.18W at 10:20 AM, with a panel temperature of 47°C. Conversely, the lowest power output was 66.95W at 2:00 PM, indicating a decline in efficiency as the day progressed. The maximum panel temperature reached 50.4°C at 12:00 PM, with a corresponding voltage of 16.15V. A gradual decrease in voltage was observed over time, with the voltage dropping from 16.45V at 45.2°C to 16.15V at 50.4°C. This trend confirms the inverse relationship between temperature and voltage, demonstrating that an increase in solar panel temperature leads to a reduction in voltage output. These findings highlight the significant impact of thermal conditions on solar panel efficiency and reinforce the need for an effective cooling system to improve performance.

Table 1. Measurement of Solar Panels with Thermal Cooling

Time	VMP (V)	Imp (A)	Pmax (W)	Solar Panel Temperature (°C)		Water Temperature (°C)	
				T Top	T Bottom	Tin	Tout
10:00	16,45	5,75	94,59	45,2	45,7	30,5	32,0
10:10	15,57	5,75	89,53	46,1	47,0	30,3	31,2
10:20	16,64	5,78	96,18	47,0	47,7	29,8	33,0
10:30	15,19	5,78	87,80	48,4	48,0	30,0	33,2
10:40	15,23	5,78	88,03	48,6	48,2	30,0	34,0
10:50	15,05	5,78	86,99	48,6	48,4	32,5	33,5
11:00	15,30	5,78	88,43	47,8	48,0	31,0	33,2
11:10	15,38	5,75	88,44	48,3	48,0	30,3	33,2
11:20	15,05	5,78	86,99	46,2	45,7	30,5	33,8
11:30	16,36	5,78	94,56	45,9	46,0	30,2	32,5
11:40	15,34	5,78	88,67	44,3	44,4	30,8	33,2
11:50	15,82	5,78	91,44	48,3	49,1	31,5	33,8
12:00	16,15	5,31	85,76	50,4	51,4	31,5	33,8
12:10	15,16	5,85	88,69	49,0	50,1	30,0	34,8
12:20	15,38	5,75	88,44	49,5	50,5	31,3	35,0
12:30	15,64	5,75	89,93	48,2	49,7	31,8	34,0
12:40	16,19	5,78	93,58	45,6	48,0	32,5	35,0
12:50	15,49	5,78	89,53	46,1	47,6	32,3	34,8
13:00	16,26	5,78	93,98	48,3	48,6	32,5	33,2
13:10	16,30	5,75	93,73	43,6	45,5	32,8	33,8
13:20	15,67	5,36	83,99	44,3	46,7	32,5	33,2
13:30	15,05	5,45	82,02	45	47,5	31,8	34,8
13:40	14,87	5,60	83,27	44,3	47,6	32,5	32,8
13:50	14,64	4,65	68,08	43,2	46,2	32,3	33,0
14:00	14,78	4,53	66,95	42,9	46,1	32,0	33,2

Table 2 displays the measurement data from a one experimental trial. The peak temperature of the solar panel reached 58.9°C at 1:10 PM, with a VMP of 12.83V and a PMAX of 28.61W. This outcome differs from the 10:00 AM measurement, in which the solar panel temperature was 50.6°C, resulting in a VMP of 13.12V and a PMAX of 61.80W. The statistics further corroborate the inverse correlation between temperature and voltage, indicating that as panel temperature rises, both voltage and power production diminish. The absorption of increased heat by the solar panel leads to a decline in its electrical performance, underscoring the necessity for an effective cooling system to sustain optimal functionality and avert thermal damage.

Voltage Comparison

Table 1 indicates that the peak thermal VMP (Maximum Power Voltage) occurred at 10:20 AM, with a value of 16.64V. The peak VMP of the solar panel lacking thermal regulation was 13.56V at 12:00 PM. The comparison in Figure 6 demonstrates that voltage under thermal regulation is generally superior to that of an uncooled solar panel. This disparity is ascribed to the cooling effect of the thermal pipe system, which aids in sustaining an appropriate panel temperature, thus improving voltage output. These findings underscore the necessity of incorporating an effective cooling system to optimize solar panel performance and augment total energy conversion efficiency.

Table 2. Measurement of Solar Panels without Thermal Cooling

Time	Vmp (V)	Imp (A)	Pmax (W)	Solar Panel Temperature (°C)	
				T Top	T Bottom
10:00	13,12	4,71	61,80	50,6	54,2
10:10	13,05	4,75	61,99	51,8	55,0
10:20	13,20	4,08	53,86	54,1	59,8
10:30	12,50	4,25	53,13	51,1	58,3
10:40	12,68	4,75	60,23	53,2	56,0
10:50	12,94	4,71	60,95	56,1	57,5
11:00	12,90	4,28	55,21	52,5	59,0
11:10	12,90	3,30	42,57	52,3	56,4
11:20	12,98	4,24	55,04	55,3	55,2
11:30	13,49	3,51	47,35	53,7	57,9
11:40	13,46	3,30	44,42	54,9	56,3
11:50	13,42	3,73	50,06	54,8	55,8
12:00	13,56	4,06	55,05	55,2	59,0
12:10	12,64	4,75	60,04	55,2	58,2
12:20	12,46	4,28	53,33	57,2	57,1
12:30	13,34	3,73	49,76	56,2	58,2
12:40	13,42	2,49	33,42	56,8	59,7
12:50	13,42	3,39	45,49	55,9	57,8
13:00	12,38	2,5	30,95	57,4	57,4
13:10	12,83	2,23	28,61	58,9	57,9
13:20	13,09	2,16	28,27	58,7	56,6
13:30	12,64	3,69	46,64	58,1	58,8
13:40	13,31	3,51	46,72	57,7	56,9
13:50	13,01	2,87	37,34	53,7	57,9
14:00	12,60	3,26	41,08	52,5	52,8

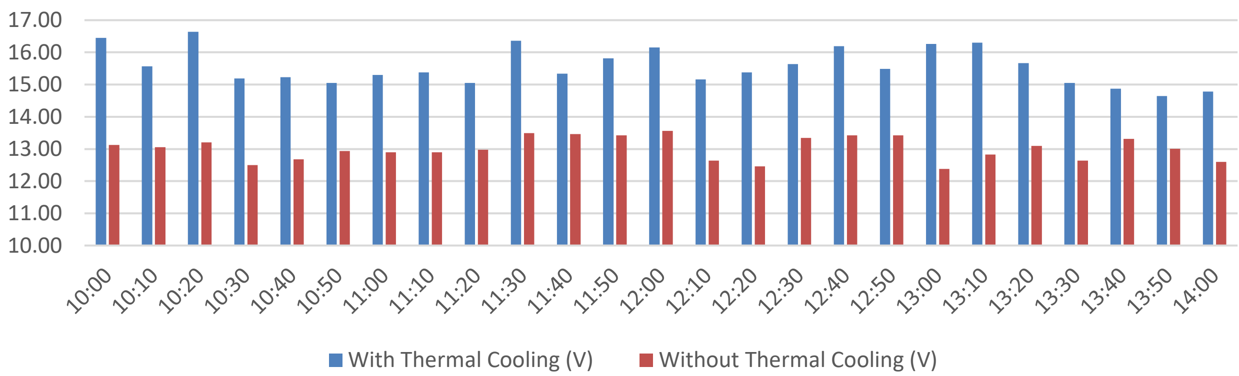

Figure 6. VMP comparison of the system with thermal and without thermal regulation

Power Output Comparison

Table 1 indicates that the peak maximum power output (PMAX) observed in the thermally regulated photovoltaic (PV) system was 96.18W at 10:20 AM. Conversely, the peak PMAX for the non-cooled solar panel was markedly inferior, attaining at 61.99W at 10:10 AM. Figure 7 visually depicts this significant disparity, emphasizing the comparative trend in power generation. The results demonstrate that the PMAX of the thermally cooled solar panel regularly surpasses that of the non-cooled panel. This mismatch mostly arises from temperature regulation within the thermal system, which inhibits excessive heat accumulation, thereby preserving optimal panel efficiency. In contrast, the non-cooled solar panel undergoes increased temperature rises, resulting in a reduction in power output. Power output is determined using the equation $P = V \times I$, where PMAX is the product of VMP (Maximum Power Voltage) and IMP (Maximum Power Current). The results emphasize the importance of an efficient cooling system, as it directly enhances solar panel energy conversion efficiency.

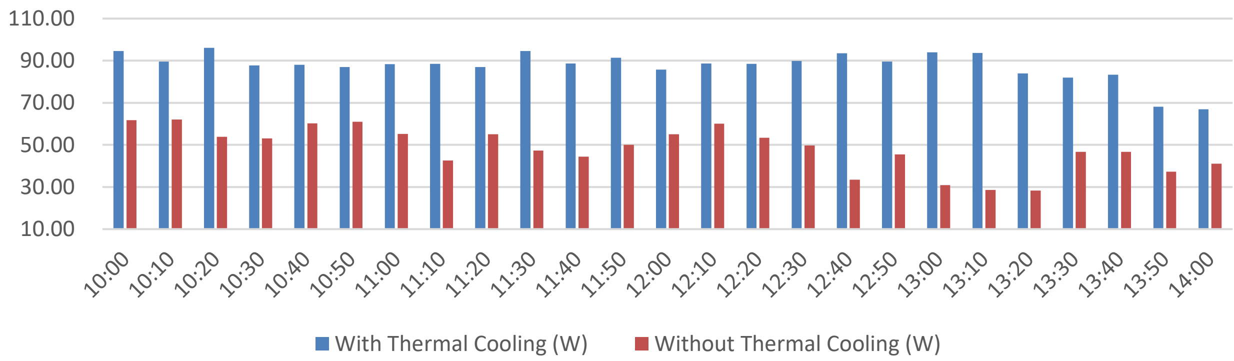

Figure 7. PMAX comparison of the system with thermal and without thermal regulation

Current Comparison

Table 1 indicates that the peak maximum power current (IMP) in the thermally regulated photovoltaic (PV) system reached 5.85A at 12:10 PM. The peak IMP in the non-cooled PV system was 4.75A, observed at 10:10 AM and 12:10 PM. The comparison in Figure 8 illustrates that the thermal cooling system improves current output by sustaining ideal operating conditions. In an uncooled solar panel, excessive heat accumulation elevates resistance within the photovoltaic cells, thus diminishing current generation. In contrast, the cooling system manages temperature, averting substantial performance decline and enabling the panel to maintain elevated current output. These findings highlight the importance of temperature regulation in photovoltaic systems, as maintaining lower operating temperatures improves overall efficiency and enhances solar panel energy conversion performance.

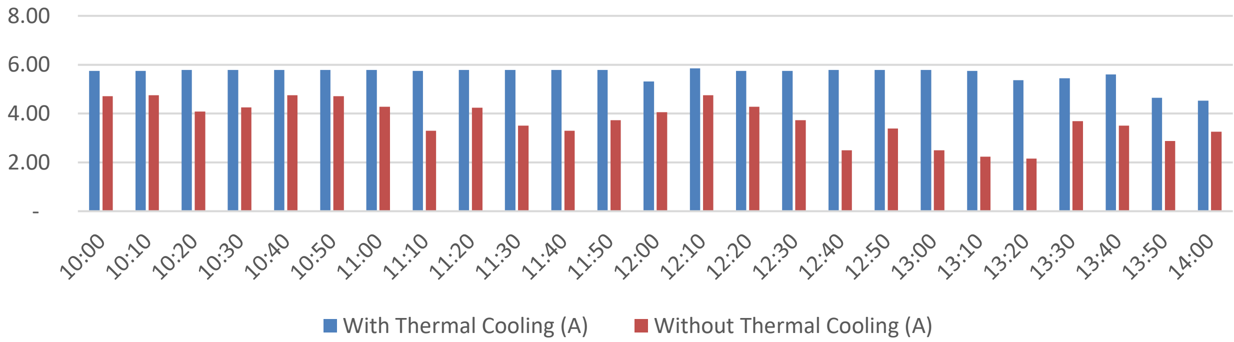

Figure 8. IMP comparison of the system with thermal and without thermal regulation

Temperature Comparison

A notable temperature disparity is evident between Table 1 (thermally regulated solar panel) and Table 2 (non-cooled solar panel). Figure 9 demonstrates that the thermally cooled solar panel consistently sustains a temperature range of around 42–50°C, in contrast to the top and lower surface temperatures of both systems. Conversely, the non-cooled photovoltaic system attains elevated temperatures, ranging from 50°C to 59°C. The statistics indicate that the thermal cooling system efficiently controls and diminishes solar panel temperature, averting excessive heat buildup. The cooling system improves solar panel efficiency and stability by sustaining a lower working temperature, hence enhancing energy conversion performance.

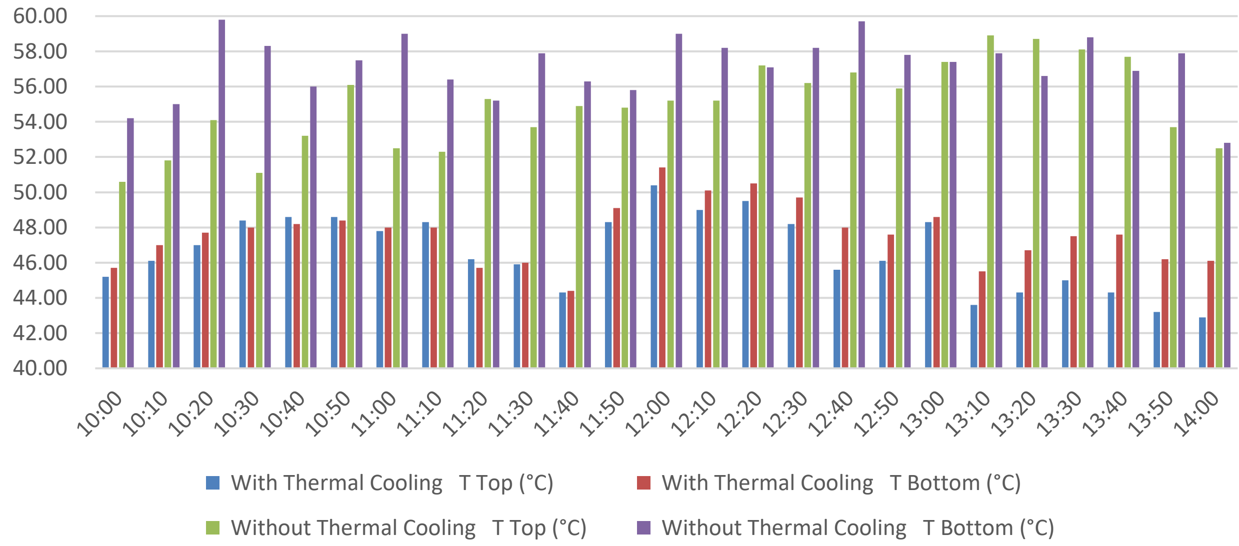

Figure 9. Top and bottom side temperature comparison of of the system with thermal and without thermal regulation

CONCLUSION

This study illustrates that the incorporation of a thermal cooling system markedly improves solar panel performance by stabilizing maximum power voltage (VMP) and maximum power output (PMAX), while concurrently lowering panel temperature. The results demonstrate that the maximum VMP seen with cooling was 16.64V, although the highest PMAX attained was 96.18W at 10:20 AM, with a panel temperature of 47°C. Conversely, the non-cooled solar panel demonstrated elevated temperatures, attaining 58.9°C at 1:10 PM, which led to a significantly reduced VMP of 12.83V and a PMAX of merely 28.61W. The results confirm the inverse correlation between temperature and solar panel efficiency, demonstrating that higher temperatures lead to a decline in both VMP and PMAX. The thermal cooling system effectively maintained lower and more stable temperatures, thereby improving panel performance. Additionally, the cooling system enhanced current output (IMP), as the thermally cooled panel recorded a higher IMP (5.85A) compared to the non-cooled panel (4.75A). These findings reinforce the effectiveness of the cooling mechanism in sustaining optimal operating conditions and improving overall energy conversion efficiency.

Environmental factors, including meteorological conditions and solar radiation intensity, affect the fluctuations in voltage and power output. Nonetheless, the results substantiate that lowering the panel temperature enhances efficiency. The solar panel equipped with a cooling system exhibited an efficiency of 43.7%, in contrast to the non-cooled panel, which attained at 24.07% efficiency.In conclusion, the incorporation of a thermal cooling system utilizing copper pipes significantly improves solar panel efficiency by regulating voltage and power production while mitigating excessive heat accumulation. These findings underscore the necessity of integrating temperature regulating mechanisms in photovoltaic systems to enhance energy conversion, boost performance, and prolong the lifespan of solar panels.

Environmental factors, including meteorological conditions and solar radiation intensity, influence fluctuations in voltage and power output. However, the results confirm that reducing panel temperature enhances efficiency. The solar panel equipped with a cooling system achieved an efficiency of 43.7%, compared to the non-cooled panel, which recorded only 24.07% efficiency. In conclusion, the integration of a thermal cooling system utilizing copper pipes significantly enhances solar panel efficiency by regulating voltage and power production while preventing excessive heat accumulation. These findings highlight the importance of incorporating temperature regulation mechanisms in photovoltaic systems to improve energy conversion, optimize performance, and extend the lifespan of solar panels.

REFERENCE

[1] J. Jamaaluddin, I. Anshory, E. Rosnawati, and D. K. Aji, "Analisa Perbandingan PWM Dan MPPT Untuk Beban Di Atas 200 W," *SinarFe7*, pp. 123–129, 2020, https://journal.fortei7.org/index.php/sinarFe7/article/view/285

[2] P. Boedi, "KOCENIN Serial Konferensi No. 1 (2020) Webinar Nasional Cendekiawan Ke 6 Tahun 2020, Indonesia," *KOCENIN Ser. Konf.*, vol. 1, no. 1, pp. 1–11, 2020.

[3] U. Penghematan, B. I. Tagihan, L. Pln, and U. A. Dahlan, "1) , 2 , 3) , 4)," vol. 2, pp. 236–240, 2024.

[4] P. Harahap, "Pengaruh Temperatur Permukaan Panel Surya Terhadap Daya Yang Dihasilkan Dari Berbagai Jenis Sel Surya," *RELE (Rekayasa Elektr. dan Energi) J. Tek. Elektro*, vol. 2, no. 2, pp. 73–80, 2020, doi: 10.30596/rele.v2i2.4420.

[5] G. R. Cahyono, P. R. Ansyah, and M. Munthaha, "Pengaruh Variasi Kecepatan Hembusan Udara Terhadap Temperatur, Daya Output dan Efisiensi Pada Pendinginan Panel Surya," *Infotekmesin*, vol. 11, no. 2, pp. 141–146, 2020, https://doi.org/10.35970/infotekmesin.v11i2.259.

[6] S. Emani, S. K. Vandrangi, G. Velidi, M. H. Ahmadi, Y. Cárdenas Escorcia, and A. Jafet Nieto Pisciotti, "Effects of wavy structure, ambient conditions and solar intensities on flow and temperature distributions in a mini solar flat plate collector using computational fluid dynamics," *Eng. Appl. Comput. Fluid Mech.*, vol. 17, no. 1, 2023, https://doi.org/10.1080/19942060.2023.2236179.

[7] I. N. Unar *et al.*, "Performance evaluation of solar flat plate collector using different working fluids through computational fluid dynamics," *SN Appl. Sci.*, vol. 2, no. 2, pp. 1–10, 2020, https://doi.org/10.1007/s42452-020-2005-z.

[8] I. Sulistiyowati, Jamaaludin, and I. Anshory, "Characteristics of Direct-Coupling Fuel Cell Injection in Renewable Energy Hybrid Power Generation Electrical Systems," *Procedia Soc. Sci. Humanit.*, vol. 3, no. c, pp. 748–756, 2022, https://pssh.umsida.ac.id/index.php/pssh/article/view/110

[9] A. Ahfas, D. R. Hadidjaja, S. Syahrorini, B. Studi Teknik Elektro, and F. Saintek, "Id Card Sebagai Charger Hp Berbasis Energi Terbarukan," *Procedia Soc. Sci. Humanit.*, vol. 0672, no. c, pp. 1467–1471, 2022, https://pssh.umsida.ac.id/index.php/pssh/article/view/237

[10] 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, pp. 1–15, 2023, https://doi.org/10.21070/acopen.8.2023.7236.

[11] I. Anshory *et al.*, "Optimization DC-DC boost converter of BLDC motor drive by solar panel using PID and firefly algorithm," *Results Eng.*, vol. 21, no. December 2023, p. 101727, 2024, https://doi.org/10.1016/j.rineng.2023.101727.

[12] Z. Arizal, A. Y. Dewi, A. Effendi, and R. Andari, "Analysis of a 735 kWp On-Grid Solar Power Plant System on the Rooftop of the Main Office of PT . Pertamina Hulu Rokan," vol. 1, no. 3, pp. 93–105, 2025, https://www.seajaet.peare-rc.org/index.php/seajaet/article/view/43

[13] S. H. Kiki, U. Prayogi, and B. Y. Dewantara, "Perancangan Tata Letak Mesin Pendingin dan Instalasi Panel Surya sebagai Supply Daya Sistem Pendingin Ruang Muat Kapal Ikan KM. Jaya Putra," *J. Tek. Elektro Uniba (JTE UNIBA)*, vol. 7, no. 1, pp. 255–260, 2022, https://doi.org/10.36277/jteuniba.v7i1.163.

[14] A. Pawawoi and Z. Zulfahmi, "Penambahan Sistem Pendingin Heatsink Untuk Optimasi Penggunaan Reflektor Pada Panel Surya," *J. Nas. Tek. Elektro*, vol. 8, no. 1, p. 1, 2019, https://doi.org/10.25077/jnte.v8n1.607.2019.

[15] M. S. Loegimin, B. Sumantri, M. A. B. Nugroho, H. Hasnira, and N. A. Windarko, "Sistem Pendinginan Air Untuk Panel Surya Dengan Metode Fuzzy Logic," *J. Integr.*, vol. 12, no. 1, pp. 21–30, 2020, http://dx.doi.org/10.30871/ji.v12i1.1698.

[16] R. Subarkah and B. Belyamin, "Pemanas Air Energi Surya Dengan Sel Surya Sebagai Absorber," *Poli-Teknologi*, vol. 10, no. 3, pp. 225–231, 2021, https://jurnal.pnj.ac.id/index.php/politeknologi/article/view/37

[17] M. Rezki, R. Rusilawati, and I. Irfan, "Optimalisasi Daya Panel Surya Menggunakan Sistem Pendingin Berbasis Air Otomatis," *J. EEICT (Electric Electron. Instrum. Control Telecommun.*, vol. 6, no. 2, 2023, http://dx.doi.org/10.31602/eeict.v6i2.12921.

[18] M. Zuhairi, Analisis Kondisi Suhu Permukaan Sel Surya Terhadap Fluktuasi Cuaca Berbasis Thermovisi. Universitas Medan Area, 2023, https://repositori.uma.ac.id/handle/123456789/21696

[19] R. Z. Fadillah *et al.*, "Perbandingan Penggunaan Panel Surya dan Turbin Angin dalam Implementasi Energi Baru Terbarukan (EBT) di Lingkungan Universitas Pertamina," *J. Teknol. Lingkung.*, vol. 22, no. 1, pp. 029–037, 2021, http://dx.doi.org/10.29122/jtl.v22i1.3247.

[20] D. Almanda and B. P. Piliang, "Perbandingan Sistem Pendingin pada Konsentrasi Water Coolant, Air Mineral, dan Air Laut Menggunakan Panel Surya Fleksibel Monocrystaline 20 Wp," *Resist. (elektRonika kEndali Telekomun. tenaga List. kOmputeR)*, vol. 2, no. 2, p. 73, 2019, https://doi.org/10.24853/resistor.2.2.73-82.

[21] I. Martati and D. Kusrihandayani, "Kaji Experimental Photovoltaic Thermal (PV/T) Pendingin Panel Surya," *Pros. 4th Semin. Nas. Penelit. Pengabdi. Kpd. Masy. 2020*, pp. 124–129, 2020, https://jurnal.poliupg.ac.id/index.php/snp2m/article/view/2430/2142