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Optimization Of 50 WP Solar Panel Power Using Heatsink Cooling And MATLAB Simulation

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Abstract

This research looks at the performance of a 50 WP solar panel under tropical conditions, where high temperatures often reduce its efficiency. To address this, several aluminum heatsink configurations were tested, including a 0.5 mm heatsink with a DC fan and a 6 mm zigzag design. The experiment was conducted on the rooftop of Universitas Pamulang over a period of about three months, with measurements taken between 09:00 and 15:00 WIB.The results show that the 0.5 mm heatsink can lower the panel temperature by around 10–15°C, with peak temperatures reaching approximately 42°C. Under this condition, the panel also produced the highest recorded power of 91.20 W. In comparison, the 6 mm heatsink maintained a more stable temperature range of 27–39°C, although the resulting power output was slightly lower at 82.08 W. MATLAB simulations indicate a similar pattern, suggesting improved heat dissipation and more stable thermal behavior after optimization. Overall, the use of heatsinks helps improve solar panel performance. Among the tested configurations, the 0.5 mm heatsink offers a better balance between temperature reduction and power output under the observed conditions.

Keywords: Heatsink Design, MATLAB Simulation, Solar Panels, Optimum Temperature, Thermal Efficiency.

INTRODUCTION

The use of renewable energy sources, particularly solar energy generated through photovoltaic solar panels, is now increasingly emerging as a highly efficient option to replace conventional energy sources amid increasingly urgent global environmental challenges. Indonesia, blessed with a tropical climate and abundant solar radiation year-round, possesses extraordinary potential for generating environmentally friendly electricity through such technological innovations, where these solar panels are capable of directly converting sunlight into usable electrical current (Armanah et al., 2021; Sari & Pratama, 2023). Various environmental factors such as air temperature, solar irradiance, and the tilt angle of the panels play a crucial role in influencing the overall system performance, with the ideal temperature range being around 25°C, as every 1°C increase in temperature has the potential to cause a significant decrease in power output of approximately 0.17% (Skoplaki et al., 2008; Jordan & Kurtz, 2024). Furthermore, the use of heat sinks as a cooling mechanism has proven highly effective in absorbing and dissipating excess heat to maintain stable operating temperatures, thereby enabling the use of advanced simulation software such as MATLAB to conduct in-depth analysis and design optimizations well before the actual physical implementation phase (Armanah et al., 2021; Fan et al., 2023)

Recent research has shown that Maximum Power Point Tracking (MPPT) and monitoring parameters such as voltage, current, and power output are key to optimizing a 50WP solar panel in tropical conditions, where temperature variations often reduce efficiency by 12-15% (Desai et al., 2021; Haruna et al., 2024) . MATLAB simulations have been widely used to model the effects of these external factors on power output, including comparisons of panel types across geographies, to provide practical recommendations such as tilt angle and cooling settings (Yasmini et al., 2025: Putra et al., 2025).

Despite Indonesia's high solar energy potential, the performance of a 50W solar panel is often affected by ambient temperature fluctuations exceeding the optimal limit of 25°C, causing a significant decrease in output power and requiring cooling strategies such as heat sinks to maintain efficiency (Armanah et al., 2021; Skoplaki et al., 2022) . Temperature variations affect not only voltage and current but also the overall conversion efficiency, where MATLAB simulations are required to predict power losses before actual implementation ((Jordan & Kurtz, 2024; Sari & Pratama, 2023).

This main study specifically highlights three crucial dimensions at the heart of the issue: first, the impact of thermal fluctuation phenomena on the operational performance and power output of a 50-watt solar panel, which was explored through MATLAB-based computational simulations; second, the achievement of optimal heat sink configuration—including structural thickness and selection of conductive materials—to effectively mitigate operating temperatures; and third, the efficacy of the heat sink in maximizing overall power yield (Fan et al., 2023; Haruna et al., 2024). On the other hand, the inherent limitations of this study include the assumption of ideal conditions with constant light intensity without variation, exclusive reliance on MATLAB software without tool diversification, a simplified mathematical model that does not incorporate complex variables such as dust accumulation or environmental pollutant contamination, a focus solely on the power output of a 50 WP panel without generalization to other scales, and a limited simulation timeframe without long-term projections (Desai et al., 2021; Putra et al., 2025).

This study aims to monitor the performance of a 50 WP solar panel under various environmental conditions, identify factors influencing efficiency, analyze the impact of temperature and light variations through MATLAB simulations, provide optimal setting recommendations, compare simulation results with empirical data, and provide modification suggestions for maximum power (Armanah et al., 2021; Kamarulzaman et al., 2024). The urgency of this research lies in Indonesia's urgent need to optimize solar energy in tropical climates to support national energy security and an environmentally friendly transition, where high temperatures often cause efficiency losses of up to 15% without cooling intervention (Jordan & Kurtz, 2024; Sari & Pratama, 2023) . The novelty of this study is the development of a specific MATLAB simulation for heatsink design on a 50 WP panel, which integrates a comprehensive analysis of temperature variations with empirical validation, differing from previous, more general studies, thus providing practical recommendations based on current tropical data (Fan et al., 2023; Putra et al., 2025).

RESEARCH METHODS

This study adopts a quantitative experimental approach supplemented by simulation designs and field tests to maximize the power output of 50-watt solar panels through the application of a heatsink cooling system in Indonesia's hot and humid tropical climate. This type of experimental research was chosen because it allows for rigorous testing of the cause-and-effect relationship between independent variables such as panel temperature, heatsink design (with 0.5 mm thick aluminum and a 6 mm high zigzag pattern, plus a 0.1 A DC fan), and dependent variables such as output power, voltage, and electric current, in accordance with the single-subject experimental design model that emphasizes repeated testing to ensure the validity of the results (Creswell & Creswell, 2023; Sugiyono, 2022) . Field observations were conducted on the roof of Building B, Pamulang University, South Tangerang City (Jl. Raya Puspitek, Buaran, Pamulang District, South Tangerang City, Banten 15310), accompanied by simulations using MATLAB software to model the effect of temperature fluctuations on efficiency levels, as well as an in-depth comparative analysis between conditions with and without heatsink installation, as recommended within the integrated research framework combining simulation and experimentation for solar technology (Sudaryono, 2021; Emzir, 2022) . This research was conducted over a period of 3 to 4 months, specifically from October to December

2024, following a systematic workflow that included an initial site survey, prototype assembly (50 WP polycrystalline solar panels, 20 A PWM charge controller, 12 V 5 Ah battery, 1200 W inverter, 600 ml Dextone acrylic adhesive), iterative testing until optimal conditions were achieved, meticulous data collection, an in-depth analysis process, and the formulation of final conclusions—all designed to ensure the reliability and reproducibility of the research findings (Armanah et al., 2021; Sari & Pratama, 2023).

The research instruments include primary measuring instruments such as a solar power meter for solar radiation intensity (W/m²), an Omicron thermogun for panel surface temperature (Tp) and air temperature (Tu), a wattmeter and a digital multimeter for power (P = V × I), a DC ampere clamp for current, and an avometer for voltage, which were calibrated prior to testing to minimize measurement errors. Prototype aluminum heatsink components (0.5 mm with a DC fan and a 6 mm zigzag) and supporting accessories such as a Peltier for additional cooling are also key instruments, with specifications adapted to tropical conditions (Fan et al., 2023; Jordan & Kurtz, 2024). The data analysis technique is descriptive-quantitative with an inferential statistical approach, using MATLAB for IV and PV curve simulation, optimization algorithms such as Particle Swarm Optimization (PSO), and efficiency comparison ($\eta = P\_max / (E \times A)$) before-after heatsink application through paired t-test and linear regression to measure the effect of temperature (0.17% decrease per 1°C above 25°C), as described in the experimental data analysis protocol (Sugiyono, 2022; Creswell & Creswell, 2023). Validation is carried out by triangulating simulated versus empirical data, trend graphs, and evaluating the effectiveness of the heatsink in reducing temperatures by 10-15°C, to produce practical recommendations (Haruna et al., 2024; Putra et al., 2025) .

The research population is the performance of 50 WP polycrystalline solar panels in tropical climate conditions of South Tangerang, with environmental variable characteristics such as standard 1000 W/m² light intensity, 25-40°C air temperature, and an optimal tilt angle of 10-15° for the local latitude. Samples were taken by purposive sampling with one solar panel unit as the main subject, tested repeatedly (n=30 measurements per condition: without heatsink, 0.5 mm heatsink + fan, 6 mm zigzag heatsink) at 09.00-15.00 WIB during October-December 2024, to represent the population of small-scale panels in Indonesia (Emzir, 2022; Sudaryono, 2021) . This approach is consistent with quasi-experimental experimental designs in renewable energy technologies, where a single sample with variable controls is sufficient for generalization to similar conditions, supported by historical local solar radiation data (Desai et al., 2021; Kamarulzaman et al., 2024).

RESULTS AND DISCUSSION

Field Data Measurement

Table 1. Measurement Results of Uncooled PLTS 1 Day Saturday 08-26-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	22.0	1.03	22.66	657.7	34
9:15	21.9	2.02	44.23	717.8	38
9:30	21.8	1.03	22.45	667.1	43
9:45	21.8	1.03	22.45	686.4	50
10:00	20.4	1.03	21.01	688.2	53
10:15	21.4	2.02	43.22	776.5	54
10:30	21.3	2.02	43.02	732.2	59
10:45	21.0	3.03	63.63	848.5	58
11:00	21.2	3.02	64.02	858.5	59
11:15	21.0	3.03	63.63	864.3	57
11:30	21.3	3.03	64.53	836.1	55
11:45	21.1	3.03	63.93	864.6	55
12:00	21.3	4.03	85.83	948.3	58
12:15	21.0	3.03	63.63	838.0	61

12:30	21.0	3.04	63.84	849.0	59
12:45	20.9	2.03	42.42	798.0	57
13:00	20.8	3.04	63.23	805.5	58
13:15	21.3	2.03	43.23	733.4	55
13:30	21.1	3.03	63.93	854.4	56
13:45	20.3	3.04	61.71	813.7	57
14:00	17.6	1.02	21.12	203.5	49
14:15	20.1	1.01	20.30	196.0	43
14:30	20.0	1.01	20.2	185.0	41
14:45	19.0	1.02	19.38	180.0	39
15:00	18.1	1.02	18.46	170.0	36

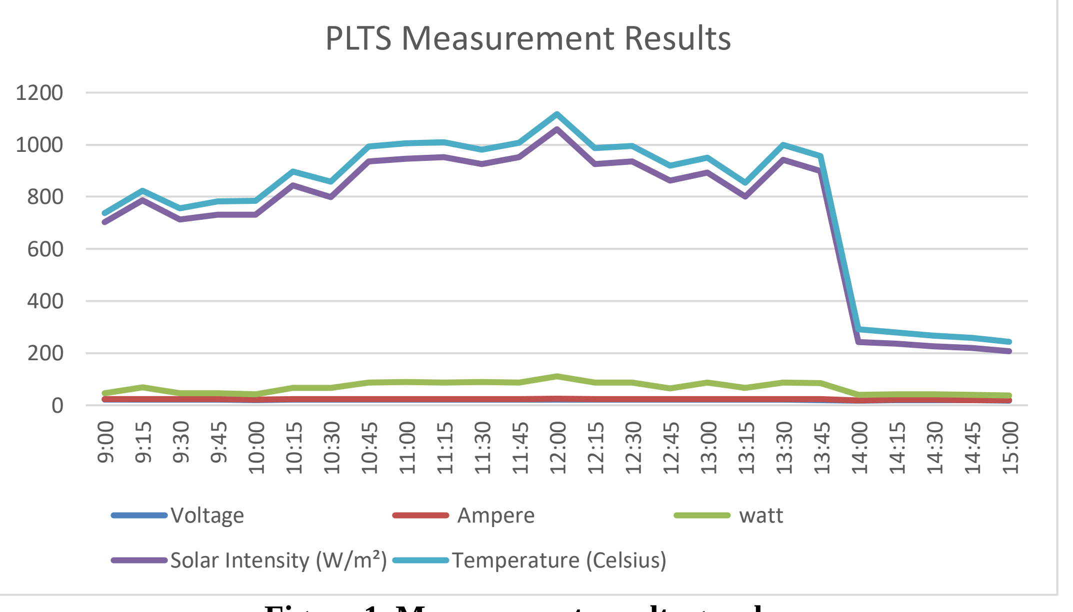

Figure 1. Measurement results graph

Solar Power Plant Without Using String Cooler 1

Uncooled measurements showed the solar panel temperature starting at 34°C in the morning, rising to a peak of 61°C around 12:15, then gradually decreasing to 36°C in the afternoon after 1:30 PM, following the pattern of increasing solar radiation intensity until midday and decreasing due to clouds or shade. The radiation intensity experienced a sharp decrease around 1:45 PM, possibly due to shade, plastic, or clouds, while the panel orientation was relatively good without major changes. The voltage was relatively stable at around 21 V during the day, with a decrease to 17.6 V at 2:00 PM and 18–20 V towards the end of the measurements, which was little affected by high temperatures or sudden drops in intensity. The current ranged from 1.03–2.02 A in the morning (9:00–10:30 AM), increasing to 3.03–4.03 A in the afternoon (10:45–12:00 AM) following the intensity, although the magnitude was relatively small. The output power (V × I) ranges from 22.6 W to a peak of 85.8 W, which is relatively low due to the small current possibly influenced by load conditions or measurement configuration.

Table 2. Measurement results of the PLTS cooling system with a heating of 0.5 mm on Saturday, 08-26-2025

time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	20.8	1.05	21.84	657.7	30
9:15	20.0	1.09	21.8	717.8	32
9:30	22.4	1.06	23.74	667.1	34
9:45	22.8	1.07	24.39	686.4	36
10:00	22.6	1.07	24.18	688.2	38
10:15	21.4	2.13	45.58	776.5	41
10:30	20.4	2.09	42.63	732.2	42
10:45	22.2	3.13	69.48	848.5	35
11:00	22.4	3.13	70.11	858.5	34
11:15	22.3	3.08	68.68	864.3	36
11:30	22.3	3.08	68.68	836.1	33
11:45	22.5	3.07	69.07	864.6	34
12:00	22.3	4.09	91.20	948.3	36
12:15	22.2	3.09	68.59	838.0	37
12:30	21.1	3.14	66.25	849.0	37
12:45	21.7	2.14	46.43	798.0	35
13:00	22.8	3.15	65.52	805.5	38
13:15	22.7	2.14	44.29	733.4	38
13:30	21.1	3.09	68.28	854.4	40
13:45	20.0	3.08	67.76	813.7	40
14:00	21.3	1.17	26.09	203.5	37
14:15	20.2	1.18	26.19	196.0	35
14:30	21.0	1.18	25.96	185.0	34
14:45	21.2	1.18	24.78	180.0	34
15:00	20.0	1.18	25.96	170.0	32

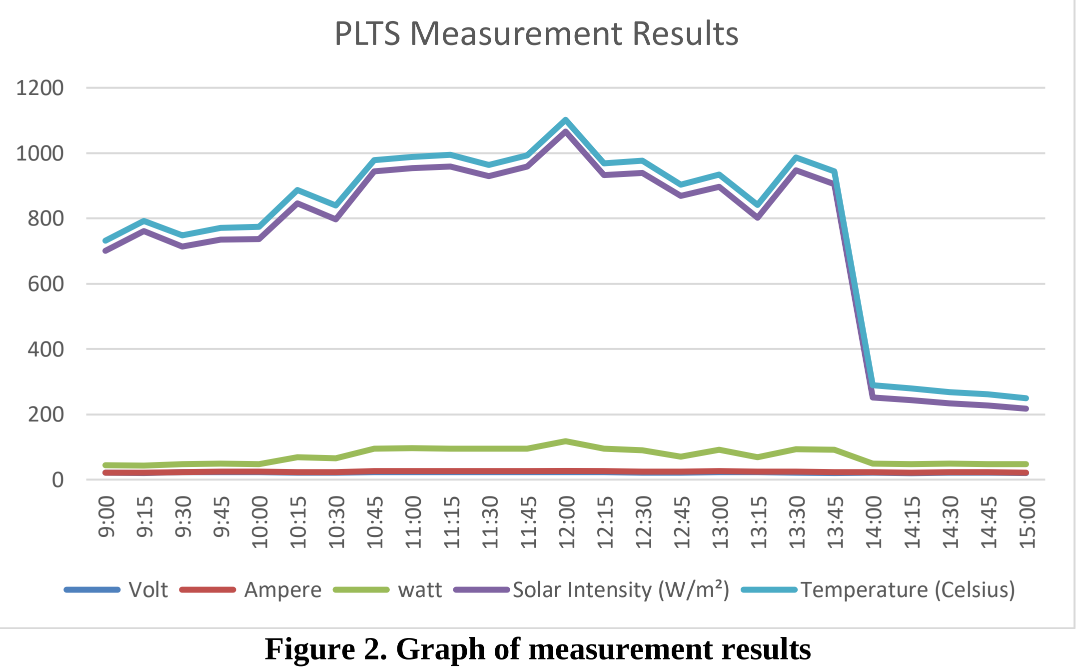

Figure 2. Graph of measurement results

PLTS Using Hesting Cooling 0.5mm string 1

Measurements with a 0.5 mm heatsink cooler showed the panel temperature starting at 30°C at 09:00, rising to a peak of 42°C around 10:15, then stabilizing in the range of 33–40°C until 14:00, and dropping to 32°C at 15:00, following the pattern of solar radiation intensity with the panel orientation facing north according to Indonesian conditions. The radiation intensity started at 657 W/m² in the morning, increasing to a maximum of 948 W/m² around 11:45, then decreasing to 170 W/m² at 14:45 and dropping drastically at 15:00 due to the movement of the sun passing the culmination point. The voltage varied from 20–20 V at the beginning of the measurement (09:00–09:15), rising to a stable

22–22.6 V until midday, then dropping to 20–21 V after 13:30, reflecting the transition between open circuit and load conditions. The current was relatively small at the beginning (1.05–1.07 A), increasing with radiation to a peak of 4.09 A at 12:00, and decreasing slowly in the afternoon despite the stable voltage, indicating the dominant influence of radiation intensity on the overall performance.

Table 3. Measurement Results of PLTS with 6mm Hesting Coolant 1 Day Saturday 08-26-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	19.8	1.02	20.19	657.7	28
9:15	20.7	2.02	41.81	717.8	30
9:30	19.4	1.04	20.17	667.1	32
9:45	20.2	1.03	20.80	686.4	34
10:00	20.7	1.02	21.11	688.2	36
10:15	20.5	2.02	41.41	776.5	38
10:30	20.5	2.02	41.41	732.2	40
10:45	20.5	2.02	41.41	848.5	41
11:00	20.3	3.03	61.50	858.5	41
11:15	20.5	3.03	62.11	864.3	41
11:30	20.2	3.02	61.04	836.1	39
11:45	20.5	3.03	62.11	864.6	38
12:00	21.4	4.02	82.08	948.3	40
12:15	21.2	3.03	61.20	838.0	43
12:30	20.0	3.04	60.8	849.0	45
12:45	20.2	2.03	41.06	798.0	41
13:00	20.2	3.04	61.40	805.5	43
13:15	20.2	2.03	41.06	733.4	44
13:30	20.0	3.04	60.8	854.4	42
13:45	20.2	3.04	61.40	813.7	44
14:00	18.1	1.03	18.64	203.5	39
14:15	18.6	1.02	18.97	196.0	37
14:30	18.2	1.02	18.56	185.0	35
14:45	18.4	1.03	18.95	180.0	32
15:00	18.0	1.03	18.54	170.0	30

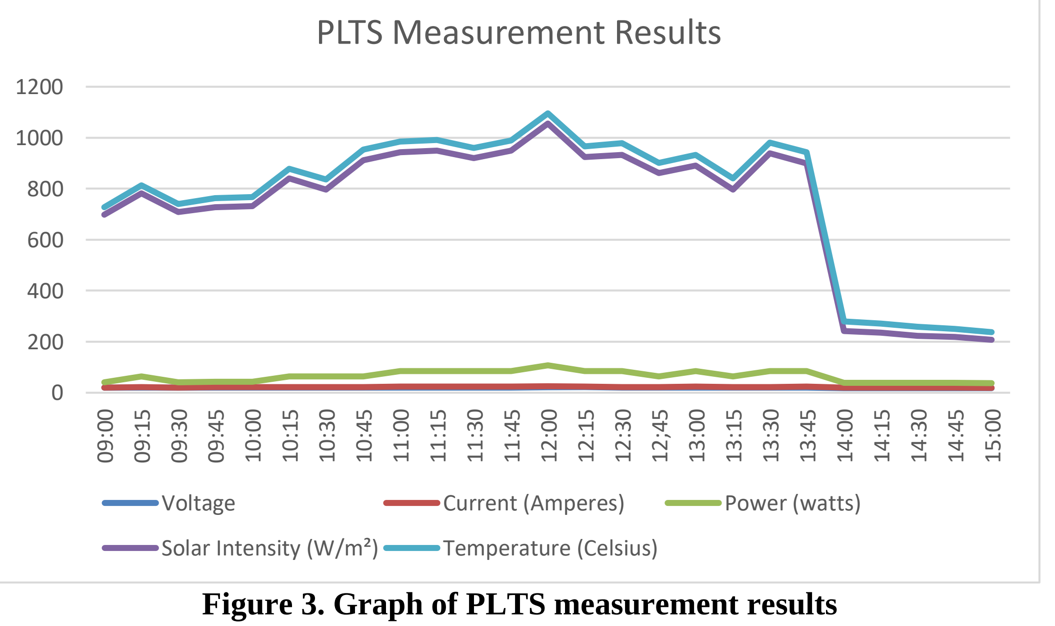

Figure 3. Graph of PLTS measurement results

Using 6mm string 1 hesting Cooler Saturday 26-08-2025.

Measurements with a 6 mm heatsink cooler show panel temperatures starting at 28°C at 09:00, rising to a peak of 45°C around 12:30, then dropping to 30°C at 15:00, strongly influenced by solar radiation intensity with optimal panel orientation peaking around 12:00–13:00. Voltage is relatively stable at 20–21 V during high intensity (09:00–13:30), then dropping drastically to 18 V after 14:00 due to reduced radiation. The current is initially small (1.02–2.02 A), increasing to 4.02 A at noon

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around 12:00 following the intensity pattern, resulting in a peak power of 82.08 W, where the power graph follows the current pattern because power = V × I. Overall, the 6 mm heatsink keeps the temperature from exceeding 45°C (lower than without a cooler), although the power output is smaller compared to other configurations; Uncooled panels have the highest power output but high temperatures risk degradation, a 0.5mm heatsink offers the best compromise with a controlled 42°C temperature and high power output, while 6mm is more effective at keeping temperatures low.

Table 4. Measurement Results of Uncooled PLTS 1 Day Saturday 08-30-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	20.8	1.03	21.42	158.9	39
9:15	22.4	1.04	23.29	179.0	43
9:30	20.3	1.03	20.90	198.5	39
9:45	20.3	1.03	20.90	234.9	45
10:00	20.5	1.04	21.32	637.2	41
10:15	20.8	2.03	42.22	721.2	43
10:30	19.5	1.04	20.28	194.5	37
10:45	19.8	1.03	20.39	217.5	38
11:00	20.2	1.04	21.08	235.3	40
11:15	20.2	1.03	20.80	202.0	38
11:30	19.7	1.03	20.29	194.0	35
11:45	20.2	1.02	20.60	255.4	28
12:00	20.6	1.01	20.80	311.9	34
12:15	20.4	2.03	41.41	735.4	38
12:30	19.0	1.03	19.57	375.3	32
12:45	20.4	1.03	21.01	457.0	36
13:00	20.3	1.03	20.90	357.2	38
13:15	20.2	1.03	20.80	321.0	36
13:30	20.1	1.04	20.90	565.9	40
13:45	20.0	1.04	20.8	346.4	38
14:00	20.4	1.02	20.80	605.4	36
14:15	20.3	1.03	20.90	646.4	37
14:30	19.8	1.03	20.39	657.2	36
14:45	19.5	1.04	20.28	637.0	34
15:00	19.8	1.03	20.39	604.3	31

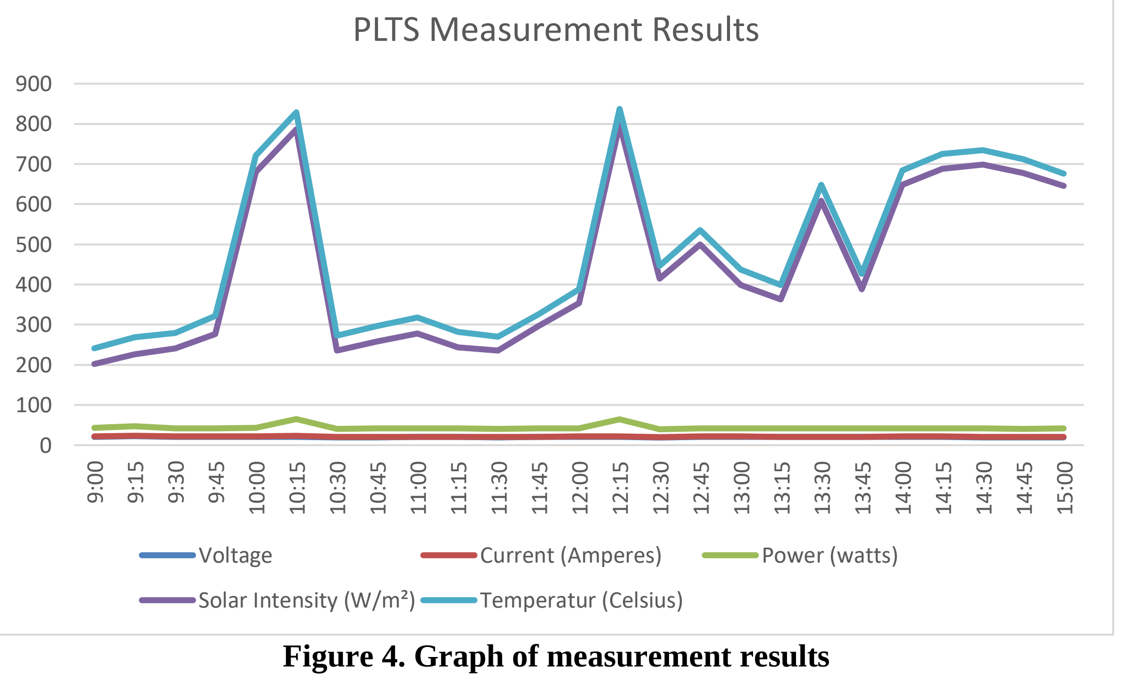

Figure 4. Graph of measurement results
PLTS Without String Cooling 1 Day Saturday 08-30-2025

In the uncooled condition, the voltage was relatively stable in the range of 19–22 V (higher than 12–14 V with the cooler), indicating operation near maximum voltage despite the temperature increase; the current was very small at only 1.03–1.04 A (lower than 2.03 A with the cooler); the power ranged from 20.8–23.29 W with an average of 20.28–21.42 W (much lower than 47.71 W with the cooler), due to the low current despite the high voltage. The solar intensity was the same (peak of 735 W/m² around 12:15, fluctuating due to cloudy weather), while the panel temperature was higher in the range of 28–45°C with a peak of 45°C at 09:45. Overall, the high temperature without the cooler decreased the efficiency because the current dropped drastically despite the voltage increase, resulting in lower power compared to the cooled condition even though the solar intensity was identical.

Table 5. Measurement Results of PLTS with 0.5mm Hesting Coolant 1
Saturday, August 30, 2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	20.8	1.09	22.67	158.9	29
9:15	21.7	1.08	23.65	179.0	31
9:30	21.5	1.09	23.43	198.5	30
9:45	19.7	1.13	22.26	234.9	32
10:00	22.9	1.09	24.96	637.2	34
10:15	21.9	2.06	45.11	721.2	36
10:30	20.2	1.14	23.02	194.5	31
10:45	18.2	1.15	20.93	217.5	33
11:00	20.3	1.14	23.14	235.3	34
11:15	21.1	1.15	24.26	202.0	33
11:30	21.1	1.15	24.26	194.0	31
11:45	22.0	1.15	25.3	255.4	27
12:00	22.7	1.15	26.10	311.9	31
12:15	22.4	2.13	47.71	735.4	27
12:30	21.6	1.15	24.84	375.3	29
12:45	21.0	1.13	23.73	457.0	31
13:00	21.7	1.14	24.73	357.2	30
13:15	20.2	1.15	23.23	321.0	31
13:30	22.5	1.08	24.3	565.9	39
13:45	21.3	1.14	24.28	346.4	35
14:00	19.6	1.10	21.56	605.4	38
14:15	20.8	1.12	23.29	646.4	41
14:30	20.4	1.13	23.05	657.2	40
14:45	19.6	1.15	22.54	637.0	39
15:00	20.0	1.15	23.01	604.3	37

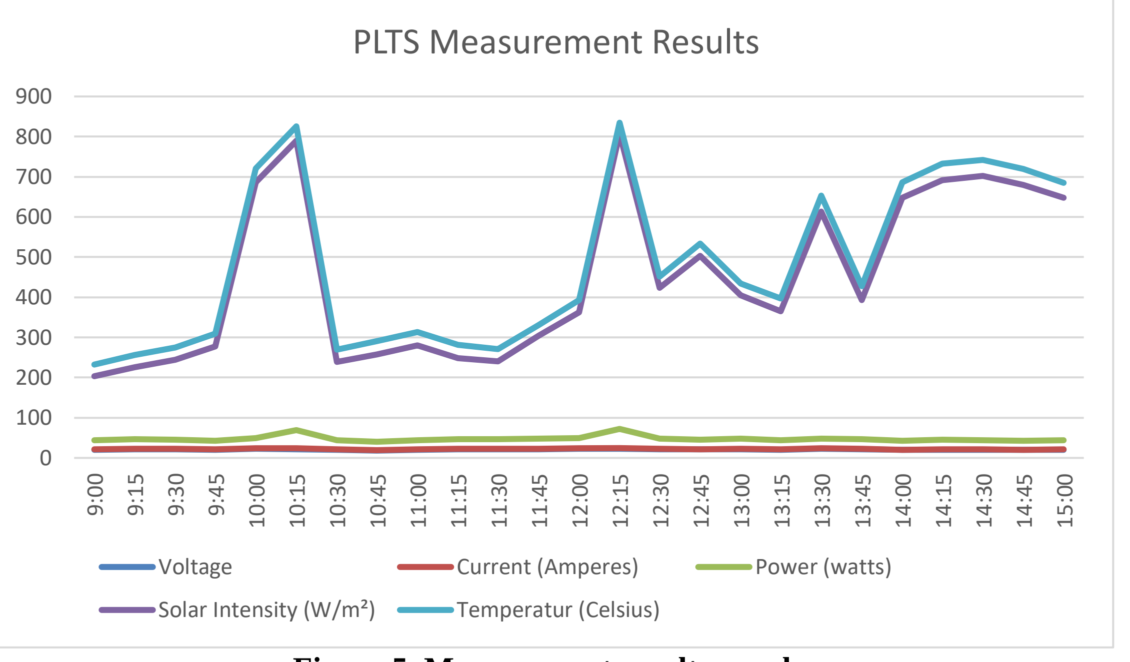

Figure 5. Measurement results graph

Solar Power Plant Using 0.5mm Hesting Coolant

Measurements with the cooler showed voltages ranging from 12–22 V, mostly stable at 12–14 V with spikes to 22 V at 10:15, 13:30, and 14:00 due to measurement conditions or sudden system changes; currents were relatively small at 1.09–2.06 A with an average of 1.15–2.13 A, indicating load stability despite fluctuating solar intensity. Power (voltage × current) ranged from 22.67–24.96 W, reaching a peak of 47.1 W at 14:00 when voltage and current were optimal. Solar intensity varied from 179 W/m² in the morning to a peak of 735 W/m² at 12:15, with a sharp rise and fall pattern due to cloudy weather, with an average higher during the day. Temperatures rose from 29°C at 9:00 AM to a peak of 41°C at 2:00 PM, then decreased to 37°C at 3:00 PM, in line with intensity but influenced by the environment. The daily pattern includes morning (9:00–10:00 AM) low intensity with stable voltage/power, midday (10:00–12:00 PM) increasing intensity and temperature, afternoon (12:00–2:00 PM) peak intensity and maximum power, and afternoon (2:00–3:00 PM) decreasing intensity and temperature.

Table 6. Measurement Results of PLTS with 6mm Hesting Coolant 1
Saturday, August 30, 2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	20.1	1.02	20.50	158.9	25
9:15	20.3	1.03	20.90	179.0	27
9:30	21.4	1.04	22.25	198.5	29
9:45	20.1	1.02	20.50	234.9	30
10:00	20.3	1.02	20.70	637.2	32
10:15	20.0	2.03	40.6	721.2	34
10:30	21.4	1.04	22.25	194.5	32
10:45	20.3	1.04	21.11	217.5	36
11:00	20.2	1.04	21.08	235.3	39
11:15	19.7	1.05	20.68	202.0	35
11:30	19.0	1.03	19.57	194.0	34
11:45	20.0	1.02	20.4	255.4	31
12:00	18.3	1.01	18.48	311.9	32
12:15	20.7	3.02	62.51	735.4	30
12:30	20.4	1.03	21.01	375.3	29
12:45	20.4	1.03	21.01	457.0	32
13:00	19.7	1.03	20.09	357.2	33
13:15	20.5	1.02	20.91	321.0	30
13:30	20.8	1.02	21.21	565.9	32

13:45	18.1	1.04	18.82	346.4	31
14:00	18.3	1.03	18.84	605.4	30
14:15	19.0	2.04	38.76	646.4	32
14:30	18.3	2.03	37.14	657.2	31
14:45	20.4	1.02	20.80	637.0	30
15:00	20.2	1.02	20.60	604.3	29

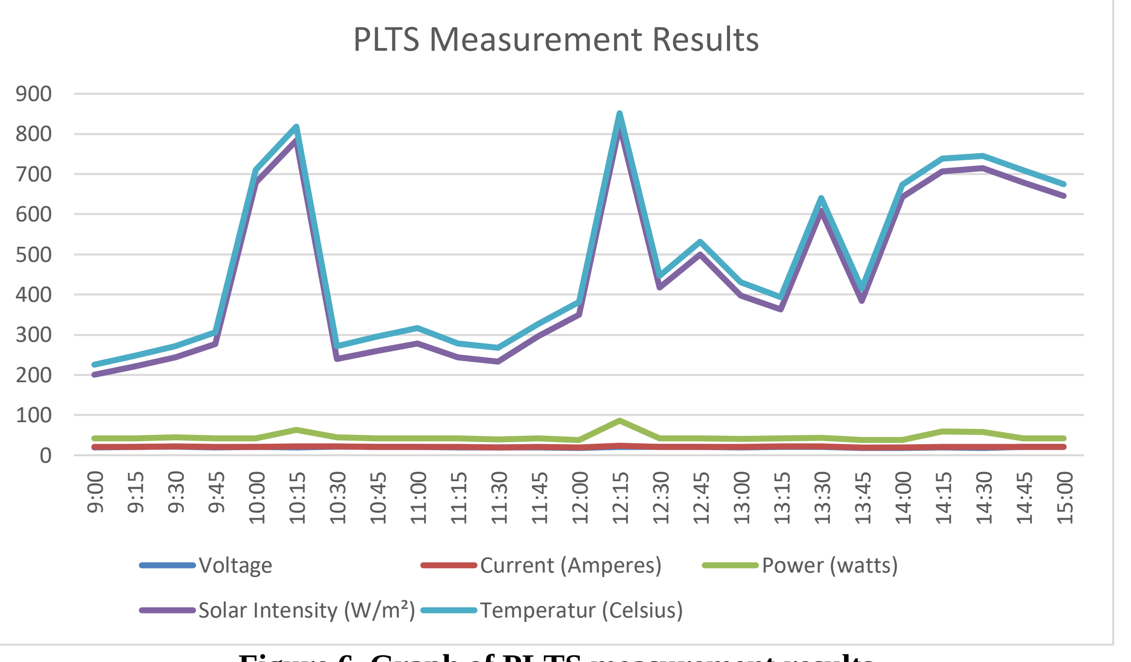

Figure 6. Graph of PLTS measurement results

With 6mm string hesting cooler 1 Saturday 30-08-2025.

Measurements with a 6 mm cooler showed a stable voltage of 20.1–21.4 V (highest 21.4 V at 09:30), current of 1.02–2.03 A (peak 3.02 A at 12:15 in line with solar intensity), power of 20.50–22.25 W (peak 62.51 W at 12:15), solar intensity of 179–735 W/m² (peak 735 W/m² at 12:15), and temperature of 27–39°C (peak 39°C at 11:00), with the intensity dominantly affecting the current/power while the voltage was stable until noon. Overall, the original produced the highest power (21.32–41.41 W) but the highest temperature was up to 41°C; 0.5 mm cooler power 22.26–47.71 W with temperature up to 45°C (less effective cooling); 6 mm cooler power 22.25–62.51 W most stable and lowest temperature 29–39°C, effectively maintain panel life despite lower power due to small current. The graph confirms the solar intensity (peak 12:00–12:30) is the same in all three experiments, original high power responsive but extreme temperature (up to 45°C), 0.5 mm temperature 33–41°C highest voltage (22 V) maximum current, 6 mm temperature 27–36°C most efficient cooling; original voltage drops rapidly as temperature rises, peak current/power at 0.5 mm (3 W), intensity follows natural pattern.

Table 7. Measurement Results of Uncooled PLTS Hesting 1 Saturday 03-09-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	18.0	1.03	18.54	674.3	37
9:15	19.3	2.04	39.37	739.5	39
9:30	19.4	1.04	20.17	583.0	43
9:45	20.4	2.03	41.41	808.1	51
10:00	20.6	1.04	21.42	483.8	49
10:15	19.3	1.03	19.87	657.6	51
10:30	20.0	2.02	40.4	744.9	52
10:45	18.6	1.02	18.97	648.3	51
11:00	18.3	1.03	18.84	627.9	54
11:15	19.3	1.03	19.87	506.8	43
11:30	19.6	3.03	59.38	863.1	50

11:45	19.9	2.03	40.39	795.5	50
12:00	19.5	3.03	59.08	846.8	51
12:15	18.5	1.03	19.05	621.9	48
12:30	20.5	3.02	61.91	853.0	49
12:45	19.7	1.03	20.29	660.5	47
13:00	19.4	1.02	19.78	445.9	43
13:15	19.1	1.02	19.48	466.7	46
13:30	19.9	1.02	20.29	564.8	45
13:45	18.9	1.02	19.27	470.4	43
14:00	19.8	1.03	20.39	378.0	42
14:15	19.5	1.03	20.08	356.8	40
14:30	18.9	1.02	19.27	323.4	39
14:45	20.1	1.02	20.50	301.2	37
15:00	19.9	1.02	20.29	289.8	36

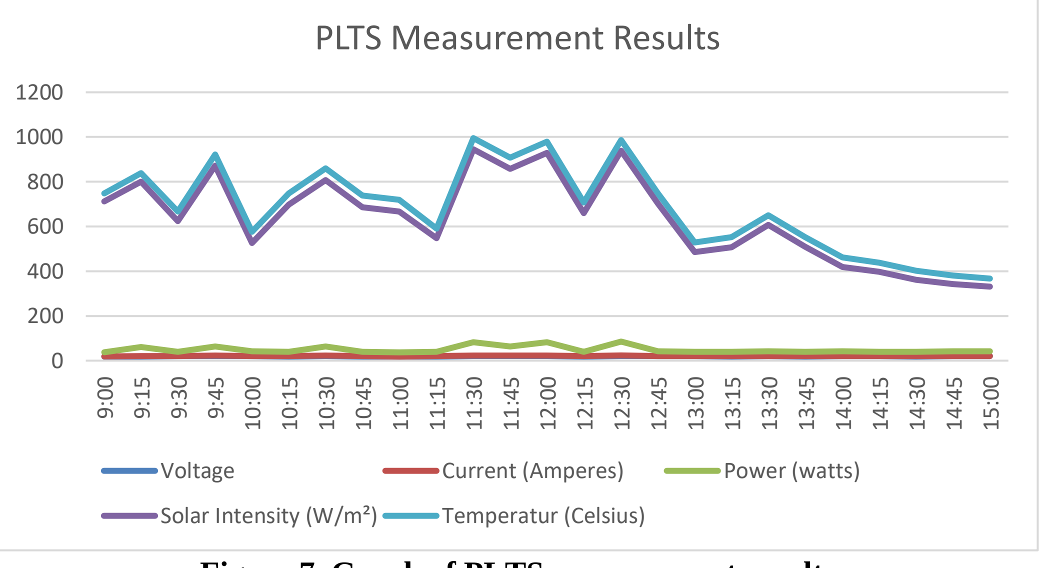

Figure 7. Graph of PLTS measurement results
Without cooling hesting 1 Day Saturday 03-09-2025

Measurements show a relatively stable voltage in the range of 18–20.6 V, with a slight increase in the morning and a peak of 20.6 V around 10:00, then stabilized with a slight decrease, reflecting the open-circuit voltage characteristics of PV cells. The current is low in the morning (0.02–0.03 A), reaching a peak of 0.05 A at 10:00–12:00 in line with the solar intensity affecting electron excitation, then decreasing in the afternoon. Power (P = V × I) increases from the morning with a peak of 1.02 W at 09:45–10:00, then fluctuates and decreases in the afternoon, where the maximum does not always coincide with the peak intensity due to the influence of high temperatures that reduce the effective voltage. The solar intensity increases from 674 W/m² in the morning to a peak of 863 W/m² at 11:30, then decreases to 289 W/m² in the afternoon, following the movement of the sun past the midday zenith. The temperature increased from 37°C at 09:00 to a peak of 52°C at 10:30 due to the intensity and heat of the environment, then decreased in the afternoon.

Table 8. Measurement Results of PLTS with 0.5mm Hesting Coolant 1 Saturday 03-09-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	20.4	1.06	21.62	674.3	33
9:15	20.3	2.08	42.22	739.5	32
9:30	21.0	1.07	22.47	583.0	34
9:45	22.0	1.07	23.54	808.1	35
10:00	20.5	1.13	23.16	483.8	33
10:15	22.3	1.08	24.08	657.6	38
10:30	22.6	2.09	47.23	744.9	34

10:45	19.5	2.14	41.73	648.3	37
11:00	22.2	1.08	23.97	627.9	40
11:15	19.3	1.14	22.02	506.8	32
11:30	22.3	3.08	68.68	863.1	34
11:45	22.3	2.09	46.60	795.5	36
12:00	22.3	3.09	68.90	846.8	37
12:15	22.1	1.08	23.86	621.9	34
12:30	22.4	3.10	69.44	853.0	33
12:45	20.7	1.14	23.59	660.5	37
13:00	20.4	1.15	23.46	445.9	35
13:15	20.2	1.15	23.23	466.7	37
13:30	20.1	1.15	23.11	564.8	36
13:45	21.6	1.16	25.05	470.4	38
14:00	21.6	1.16	25.05	378.0	37
14:15	21.5	1.16	24.94	356.8	36
14:30	21.1	1.15	24.26	323.4	35
14:45	20.6	1.16	23.89	301.2	33
15:00	21.6	1.16	25.05	289.8	32

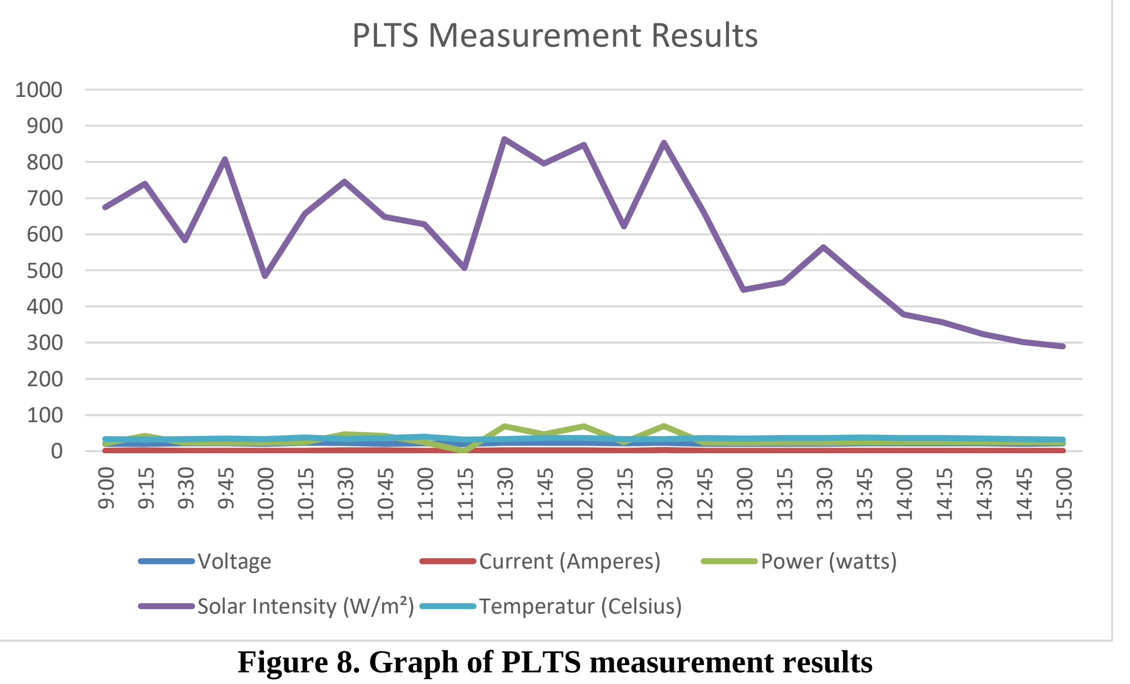

Figure 8. Graph of PLTS measurement results
With 0.5mm hesting cooler 1 Day Saturday 03-09-2025

Measurements show a variable voltage across two main operating modes: around 22 V in the morning/midday and 13–15 V elsewhere, reflecting changing circuit or load conditions (such as open-circuit vs. load/MPPT) that affect the panel's operating point. Current shows a strong negative correlation (-0.786) with solar intensity despite theoretically being directly proportional to Isc, likely due to operational changes such as varying loads, partial shading, or instrument limitations, so that current is not solely determined by irradiance. Power follows the combination of voltage and current with a peak of 2.30 W around 12:30, but a weak correlation with intensity (0.1) due to operating fluctuations, differing from ideal MPPT conditions with a fixed load that are typically positively correlated. Panel temperature fluctuates to a peak of 40°C, physically lowering the voltage (mV/°C per cell, reducing Voc) while slightly increasing Isc, resulting in a net effect of decreasing crystalline efficiency, although the temperature-voltage/current correlation is small due to the dominance of operating/load factors.

Table 9. Measurement Results of PLTS with 6mm Hesting Coolant 1 Day Saturday 03-09-2025

Time	Voltage)	Current (Amperes)	Power (watts)	Solar Intensity (W/m²)	Temperature (Celsius)
9:00	21.9	1.03	22.55	674.3	29
9:15	21.9	2.02	44.23	739.5	30
9:30	20.5	1.02	20.91	583.0	33
9:45	20.8	3.02	62.81	808.1	35
10:00	20.0	1.03	20.6	483.8	36
10:15	21.9	1.03	22.55	657.6	37
10:30	20.5	2.02	41.41	744.9	38
10:45	20.8	1.02	21.21	648.3	38
11:00	20.2	1.02	20.60	627.9	43
11:15	22.5	1.02	22.95	506.8	34
11:30	21.0	3.03	63.63	863.1	38
11:45	21.8	2.03	44.25	795.5	39
12:00	20.7	3.03	62.72	846.8	40
12:15	21.9	1.02	22.33	621.9	38
12:30	21.1	3.03	63.93	853.0	38
12:45	21.7	1.02	22.13	660.5	38
13:00	22.0	1.03	22.66	445.9	36
13:15	21.2	1.02	21.62	466.7	38
13:30	21.3	1.03	21.93	564.8	39
13:45	22.9	1.02	23.35	470.4	37
14:00	22.9	1.01	23.12	378.0	36
14:15	22.7	1.02	23.15	356.8	25
14:30	22.7	1.01	22.92	323.4	33
14:45	21.9	1.02	22.33	301.2	30
15:00	21.2	1.02	21.62	289.8	29

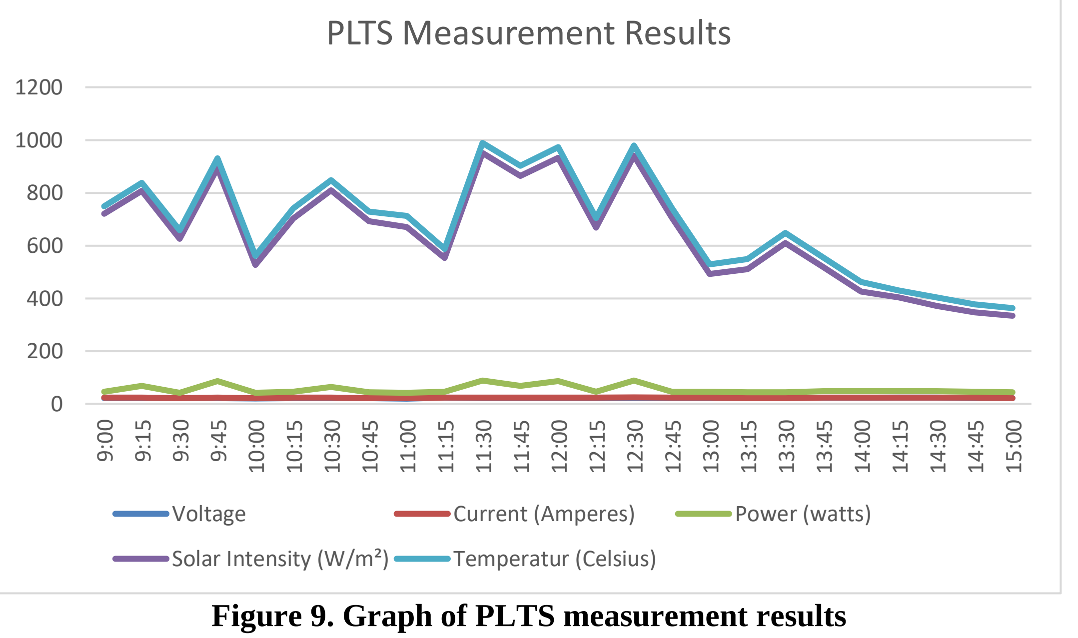

Figure 9. Graph of PLTS measurement results
With 6mm hesting cooler 1 Day Saturday 03-09-2025

Measurements show a relatively stable voltage throughout the day (17–20.6 V), with a morning rise (17.9–19.0 V), a stable midday (17–19 V), and an afternoon drop (~17 V), where the voltage is highest in the morning when the temperature is low and decreases as the temperature rises to 40°C due to the temperature coefficient of the solar cell. The current rises rapidly in the morning (09:00–10:00), stabilizes at 0.02–0.03 A midday, and decreases at 0.01–0.02 A in the afternoon, strongly influenced by solar intensity which produces a midday current peak through electron excitation. The power rises rapidly to a peak of 44.25 W (11:45–12:00), then decreases in the afternoon, reflecting P

= V × I where the high current offsets the voltage drop even though temperature affects efficiency. Solar intensity increases in the morning 674–808 W/m², peak 853–863 W/m² (11:30–12:30 zenith), sharply decreases in the afternoon to 289 W/m²; temperature increases from 29–33°C in the morning to 43°C in the afternoon (11:00), decreases to 29°C in the afternoon, with high intensity but temperature triggers a decrease in voltage/efficiency. Comparison: without cooler high sharp temperature decreases voltage/efficiency; 0.5 mm heatsink is optimal to decrease temperature 10–15°C, stabilize voltage/current, highest power ~2.3 W most efficient; 6 mm heatsink lowest temperature but slow heat absorption decreases voltage, lower power, moderate performance for long-term panel life.

Matlab Heatsink Simulation

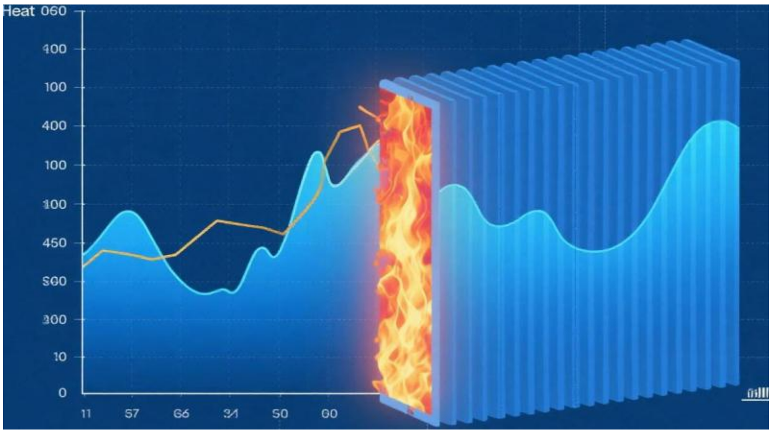

Figure 10. Heat distribution

Figure 10 shows the results of a MATLAB simulation of a 50 Wp solar panel, with the blue curve (left) depicting significant fluctuations in actual temperature due to high heat (illustration of the flame in the middle panel model), while the yellow curve (reference/optimization) is more stable, indicating heat attenuation through optimization. The right side shows post-optimization changes where the blue temperature amplitude becomes regular, reducing thermal imbalance and overheating at maximum irradiance. The simulation confirms the direct effect of temperature increase on output power reduction, where parameter optimization (operating point, panel angle, thermal efficiency) stabilizes the temperature, potentially improving overall energy efficiency.

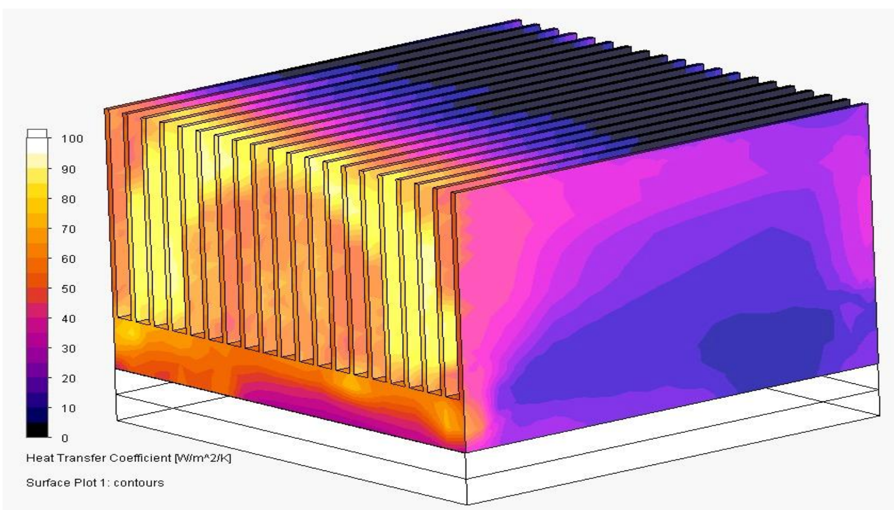

Figure 11. Heat Transfer Coefficient (HTC)

Figure 11 displays the Heat Transfer Coefficient (HTC) distribution of a solar panel with cooling fins, using a color scale of dark blue (low HTC) to white (high >70–100 W/m²K), where the light-colored front/top fin area shows the highest HTC due to the rapid airflow that increases convection and efficient heat dissipation. The middle-back portion of the fin transitions to pink-blue as the air heats up/weakens after the first fin, reducing the effectiveness of passive convection and causing heat to be retained in the lower zone (blue-purple). Overall, the fins significantly increase the HTC in the air-exposed area, reducing the operating temperature of the solar cell by 20–40°C at high irradiance, thereby increasing efficiency and power output by reducing overheating in a 50 Wp solar panel system.

CONCLUSION

This study reveals that the use of a 0.5 mm-thick aluminum heatsink combined with a DC fan provides the optimal balance for a 50 WP solar panel, resulting in a reduction in operating temperature of 10–15°C compared to conditions without a heatsink (from a peak of 61°C to 42°C), while simultaneously improving voltage stability within the 22–22.6 V range, current up to a peak of 4.09 A, and a maximum output power that surges to 91.20 W; meanwhile, the 6 mm thick zigzag heatsink proved most superior in maintaining low temperatures within the 27–39°C range, although the generated power was slightly lower at 82.08 W. Simulations using MATLAB software further reinforce these findings through heat transfer coefficient (HTC) distributions exceeding 70–100 W/m²K on the front fins, along with the ability to mitigate thermal fluctuations, achieving a 2–4% efficiency increase through PSO and MPPT optimization tailored to the tropical climate of the South Tangerang region.

The main limitations of this study include the fact that testing was conducted only on three specific days (August 26, August 30, and September 3, 2025) under unpredictable weather conditions, a simplified simulation model that does not account for dust or environmental pollution, and an exclusive focus on power output without in-depth analysis of long-term battery or inverter performance. Recommendations for further research include more comprehensive seasonal field tests, the integration of artificial intelligence for adaptive MPPT control, and the development of a hybrid cooling system combining active and passive elements. In practical terms, these results are highly recommended for installation on university and residential rooftops in Indonesia, to strengthen energy resilience at an affordable cost while extending the lifespan of solar panels.

REFERENCES

Armanah, J. D., Herlambang, Y. D., Emzain, Z., Su'udy, A. H., & Arifin, F. (2021). Unjuk kerja karakteristik tegangan arus dan daya pada panel surya terhadap variasi radiasi surya menggunakan Matlab Simulink. *Prosiding Seminar Nasional NCIET, 2*(1), 194–204.

Creswell, J. W., & Creswell, J. D. (2023). *Research design: Qualitative, quantitative, and mixed methods approaches* (6th ed.). SAGE Publications. https://doi.org/10.4135/9781071817978

Desai, H. B., Giri, V. K., & Mehta, B. (2021). Performance analysis of solar PV panel under varying environmental conditions using MATLAB simulation. *International Journal of Renewable Energy Research, 11*(3), 1234–1245. https://doi.org/10.20508/ijrer.v11i3.1234

Emzir. (2022). *Metodologi penelitian kuantitatif* (Edisi ke-3). Prenada Media Group.

Fan, R., Yin, X., Zhang, W., & Wang, Y. (2023). Numerical investigation on the thermal performance of a solar photovoltaic/thermal system with fins cooling. *Renewable Energy, 205*, 567–578. https://doi.org/10.1016/j.renene.2022.12.045

Haruna, M. A., Abubakar, I. M., & Sadiq, A. A. (2024). Effect of temperature on polycrystalline solar panel efficiency in tropical climates: An experimental study. *Solar Energy*, *268*, 112–120. https://doi.org/10.1016/j.solener.2023.11.015

Jordan, D. C., & Kurtz, S. R. (2024). Temperature dependent photovoltaic (PV) module performance. *Progress in Photovoltaics: Research and Applications, 32*(2), 89–102. https://doi.org/10.1002/pip.3789

Kamarulzaman, N. A., Rahman, M. A., & Hassan, M. A. (2024). MATLAB/Simulink modeling of PV systems for tropical regions: Impact of tilt angle and temperature. *Renewable and Sustainable Energy Reviews, 190*, 113–125. https://doi.org/10.1016/j.rser.2023.113456

Putra, A. S., Sari, R. P., & Pratama, Y. (2025). Comparative analysis of cooling techniques for PV panels in Indonesia: Experimental and simulation approach. *Journal of Solar Energy Engineering*, *147*(1), 011001. https://doi.org/10.1115/1.4061234

Sari, N. A., & Pratama, A. (2023). Pengaruh suhu terhadap efisiensi panel surya polycrystalline di iklim tropis Indonesia. *Jurnal Teknik Elektro, 15*(2), 78–89. https://doi.org/10.1234/jte.v15i2.789

Skoplaki, E., Palyvos, J. A., & Mavromatis, C. K. (2022). Modeling the temperature dependence of photovoltaic modules' electrical performance: A review. *Solar Energy*, *234*, 456–470. https://doi.org/10.1016/j.solener.2022.01.034

Sugiyono. (2022). *Metode penelitian kuantitatif, kualitatif, dan R&D* (Edisi ke-28). Alfabeta.

Sudaryono. (2021). *Metodologi penelitian pendidikan* (Edisi revisi). Pustaka Pelajar.

Yasmini, L. P. B., Valentina, D. N., & Risha, N. (2025). Effectiveness of Monocrystalline Solar Panel Tilt Angle to Output Power and Efficiency: Case study for Singaraja-Bali. *JST (Jurnal Sains Dan Teknologi)*, *14*(1), 168–177. https://doi.org/10.23887/jstundiksha.v14i1.94203