

Internet of Things based solar panel cooling and monitoring system

Anjelika Febiola¹, Citra Dewi¹, Emilhan Mirshad¹, Rudi Mulya¹

¹Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang, Padang, Indonesia

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ABSTRACT

Solar energy is one of the renewable energy sources that has great potential in Indonesia, due to its abundant availability and zero greenhouse gas emissions. However, the performance of solar panels can degrade due to high temperatures generated by continuous exposure to sunlight. This research aims to design and implement an effective cooling system to increase the output power of solar panels. The system is designed with a real time remote monitoring feature using the Blynk application, and is equipped with an automatic data logging system into Google Sheets. The cooling mechanism is carried out by spraying water onto the surface of the solar panel which is activated based on a predetermined temperature threshold value (set point). The test results show that the system is able to reduce the panel temperature by 5.46°C and increase the output power by 1.76 W. The ratio of power increase to temperature decrease is recorded at 3.1 W/°C, which proves that the system is effective in keeping the panel temperature below 40°C and contributes significantly to the improvement of solar panel performance.

Corresponding Author:

Anjelika Febiola

Department of Electrical Engineering, Faculty of Engineering, Universitas Negeri Padang

Kampus UNP Pusat, Jl. Prof. Hamka, Air Tawar, Padang 25131, Indonesia

Email: febiolaanjelika@gmail.com

1. INTRODUCTION

Electrical energy plays an important role in supporting various aspects of human life. Along with the increasing population and industrial development, the need for electricity also continues to grow. To answer these challenges, the utilization of renewable energy is a strategic choice, one of which is solar energy [1]-[3]. Solar Power Plant (PLTS) utilizes sunlight as a clean and abundant energy source, and does not produce greenhouse gas emissions [4]-[7]. The potential for new and renewable energy (EBT) in Indonesia is very large, reaching 3,686 GW, while the new installed capacity is 81.2 GW in 2022 [8]. Solar panels, as the main component of solar power plants, have performance that depends on light intensity and operational temperature. Excessive exposure to sunlight can increase the panel temperature which causes a decrease in the efficiency of the solar panel [9].

Various cooling methods have been developed, such as passive cooling using PCM (Phase Change Material) [10]. Other methods use active cooling such as fans and water as a cooling medium. Active cooling using water is proven to be more effective, capable of reducing panel temperature by 35.4% and increasing power by 12.29% [11]. Previous research developed an automatic water spraying system when the panel temperature reached 40°C, but data recording was done manually, making it inefficient for long-term analysis. However, data recording is done manually, making it inefficient for long-term analysis [12]. Further development was carried out by adding Android-based monitoring features, but the use of Arduino Uno microcontrollers and additional modules was considered less efficient [13]. Further research designed a real time monitoring system using NodeMCU ESP32 and Blynk application, but has not been equipped with data logging features [14].

Based on these problems, this research develops an Internet of Things (IoT)-based solar panel cooling and monitoring system that is not only able to keep the panel temperature stable through automatic cooling, but also equipped with real-time monitoring through the Blynk application and automatic data recording through Google Sheets. This system is expected to increase the efficiency of solar panels and support the development of renewable energy optimally in Indonesia.

2. METHOD

This research was conducted by designing and testing an automatic cooling system on solar panels based on the Internet of Things (IoT) with monitoring through the Blynk application and data recording into Google Sheets. This system uses the NodeMCU ESP32 microcontroller with inputs in the form of DHT22 sensors and INA219 sensors, and relay output control to activate the pump as a cooler on solar panels. To help understand the relationship between the components used, the overall system block diagram is shown in Figure 1.

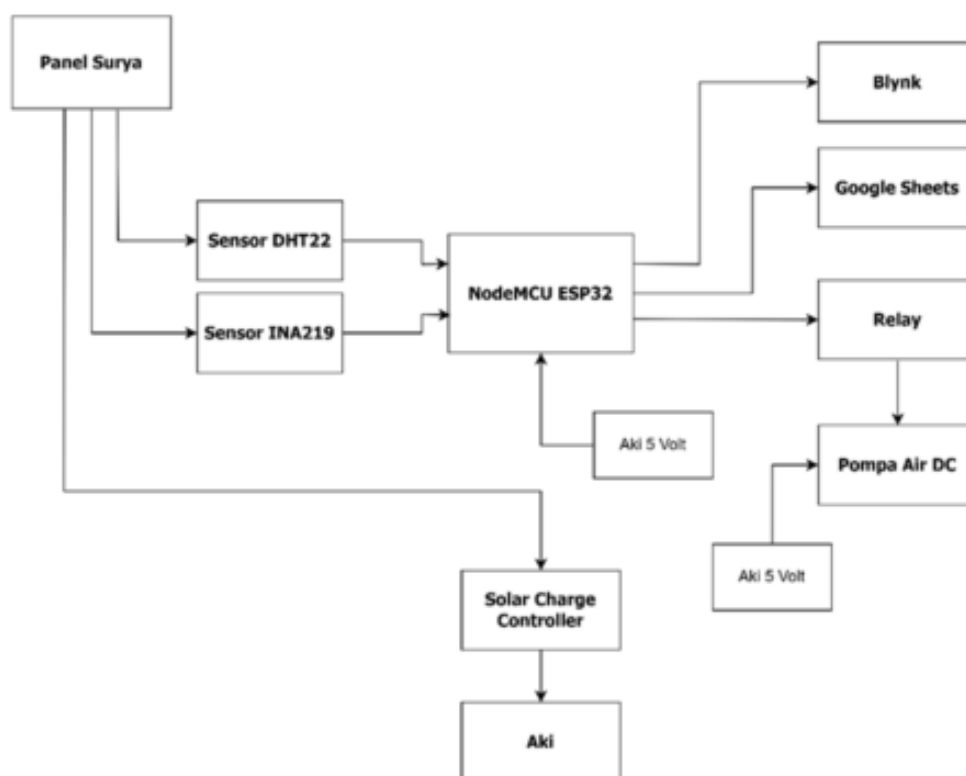


Figure 1. Block diagram

Figure 1 shows the block diagram of the Internet of Things-based solar panel cooling and monitoring system. This diagram provides a basic overview of how the tool works. It shows how all components are interconnected, with the NodeMCU ESP32 microcontroller as the control center. The following is an explanation of the function of each block in the diagram. Solar panel as a device that receives and converts sunlight into electrical energy through the photovoltaic process. NodeMCU ESP32 as a microcontroller is used to program and process input data from sensors and provide output signals to relays, as well as sending monitoring and recording data to the Blynk platform and Google Sheets. Blynk serves as an IoT platform for power monitoring which includes temperature, voltage and current data of solar panels in real time. Google Sheets as an application for storing data on temperature, current, voltage and power of solar panels over time. DHT22 temperature sensor as a temperature reader on solar panels. INA219 sensor as a reader of current and voltage output from solar panels. Relay functions as an automatic on/off switch on the DC water pump. The DC water pump is used as an output to drain water onto the surface of the solar panel. Solar Charge Controller (SCC) functions as a regulator of electricity flow from solar panels to batteries so that there is no overcharging of batteries that can cause damage. The battery functions as a store of electrical energy produced by solar panels and as a power supply for the microcontroller and DC water pump.

Flowchart or flow chart is a diagram that explains the workflow or process that shows the sequence of steps using symbols connected with arrows on the system as a whole. Flowchart of this IoT- based solar panel cooling system can be seen in Figure 2.

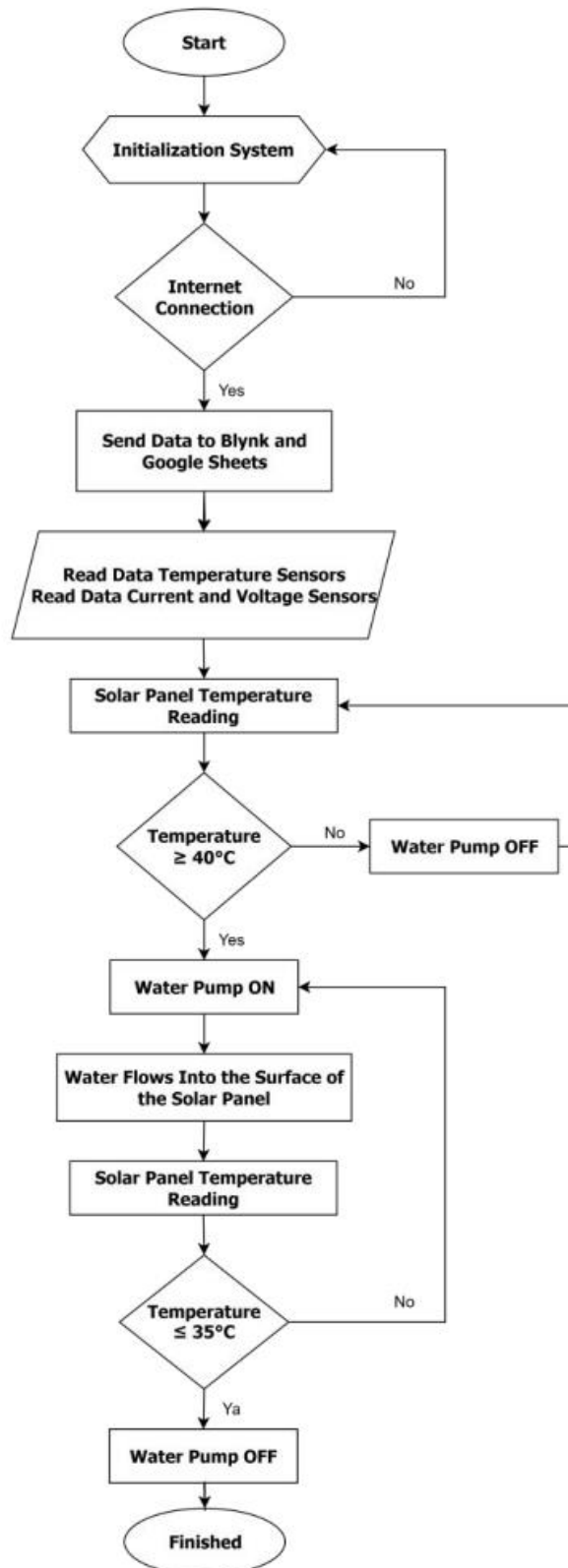


Figure 2. Flowchart of the Overall System

Hardware design consists of designing electrical control circuits and mechanical design. The control circuit in this solar panel cooling system consists of NodeMCU ESP32 as a control center that is connected to various input and output components. On the input side, this circuit receives data from the DHT22 sensor for temperature readings and the INA219 sensor for reading the current and voltage of the solar panel output. On the output side, there is a relay as an automatic on/off switch for the DC water pump to cool the solar panel. The electrical design can be seen in Figure 3.

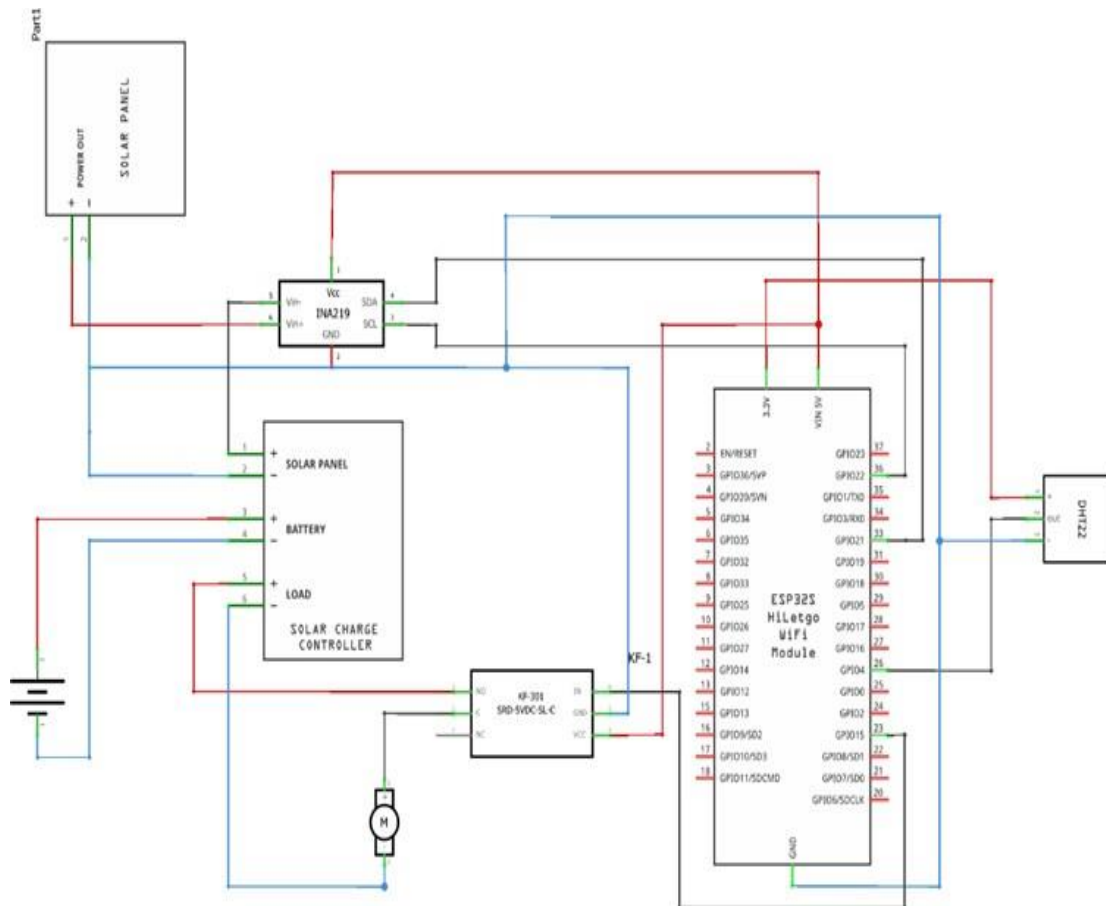


Figure 3. Control circuit

The design of the tool construction functions as a solar panel holder and cooler so that the tool works as expected. This construction consists of two boxes designed to store circuits and water tanks, with supporting poles made of alu frame boxes. The mechanical design of the system can be seen in Figure 4.

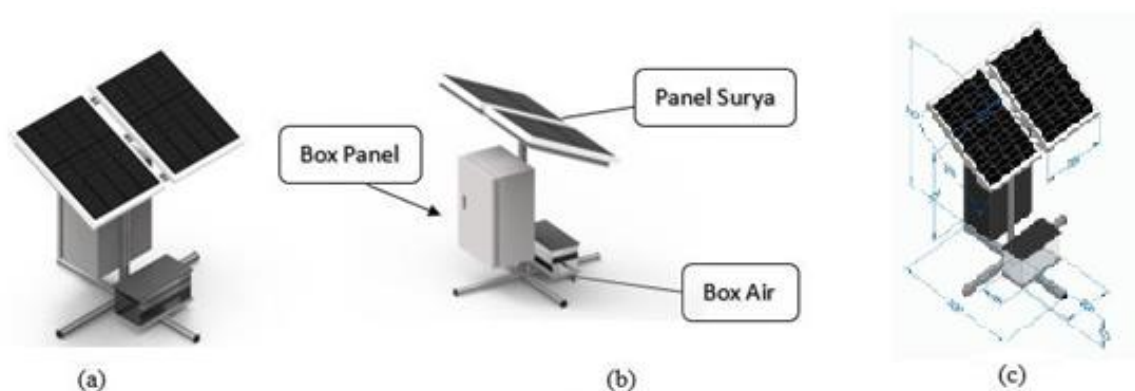


Figure 4. Tool Construction. a) Front view, b) Side view, c) Construction size design

Software design is also an important part of this system. The monitoring system in this research uses the Blynk application. Blynk is an IoT (Internet of Things) platform that can easily create mobile or web application interfaces to control and monitor devices, one of which is ESP32- based. In this final project, Blynk is used as a real time data monitoring platform of solar panel output data which includes temperature, current, voltage, and power data. The design view of Blynk can be seen in Figure 5.

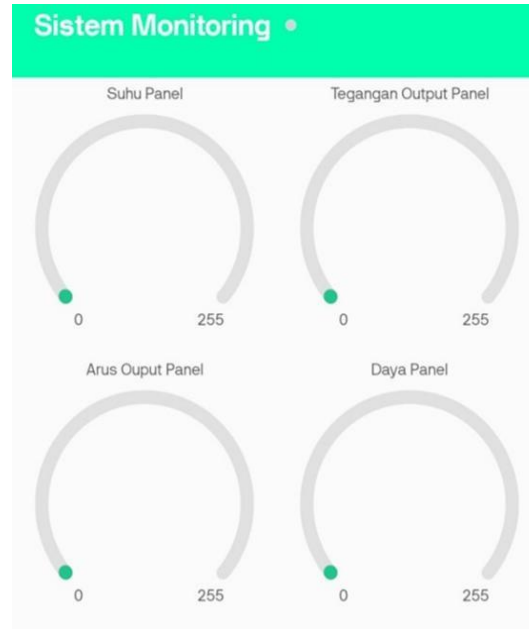


Figure 5. Data Monitoring Display in Blynk

In addition to real time monitoring on Blynk, the system is also designed to store monitoring data from time to time into Google Sheets. The design view in Google Sheets can be seen in Figure 6.

	A	B	C	D	E	F	G	H
1	Data Monitoring Pendingin Panel Surya (Update)							
2	Tanggal	Waktu	Status Pompa	Suhu (°C)	Arus (A)	Tegangan (V)	Daya (Watt)	
3								
4								
5	Data Monitoring Pendingin Panel Surya							
6	Tanggal	Waktu	Status Pompa	Suhu (°C)	Arus (A)	Tegangan (V)	Daya (Watt)	
7								
8								
9								
10								
11								
12								
13								
14								
15								
16								

Figure 6. Data Display in Google Sheets

Calculation of input power, output power and efficiency on solar panels can be calculated using the following formula [15] :

$$P_{in} = I_{rad} \times A \quad (1)$$

$$P_{out} = V \times I \quad (2)$$

$$\eta = \frac{P_{out}}{P_{in}} \times 100\% \quad (3)$$

$$\text{Peningkatan } \eta = \frac{\eta \text{ Pendingin} - \eta \text{ Tanpa Pendingin}}{\eta \text{ Tanpa Pendingin}} \times 100\% \quad (4)$$

Where P_{in} is power entering the solar panel (Watt), I_{rad} is Sunlight intensity (W/ m²), A is Solar panel area (m²), P_{out} is Solar panel output power (Watt), V is Solar panel working voltage (Volt), I is Solar panel working current (Ampere), η is Solar panel efficiency, ΔT is Average temperature difference (°C) and ΔP is Average power difference (W).

3. RESULTS AND DISCUSSION

The discussion in this section describes the test results of the automatic cooling system on solar panels equipped with real-time power monitoring features through the Blynk platform and data recording using Google Sheets. This test aims to assess the extent to which the system that has been designed is able to function properly in maintaining and increasing the output power of solar panels.

Tests were carried out using two solar panels with the same specifications and test time, using cooling and without cooling, to see and analyze the comparison of the output power produced by solar panels using a cooling system and without a cooling system. The overall test data can be seen in table 1 for the cooling system and table 2 for the system without cooling. Pembahasan dalam bagian ini menguraikan hasil pengujian dari sistem pendingin otomatis pada panel surya yang dilengkapi dengan fitur pemantauan daya secara real time melalui platform Blynk serta pencatatan data menggunakan Google Sheets. Pengujian ini bertujuan untuk menilai sejauh mana sistem yang telah dirancang mampu berfungsi dengan baik dalam mempertahankan dan meningkatkan daya keluaran panel surya.

Table 1. Cooling System Testing Data

Date	Time	Temperature (°C)	Current (A)	Voltage (V)	Power (W)	Pump Status (ON/OFF)
03/08/2025	15:19:20	31.20	0.29	20.72	6.06	OFF
03/08/2025	15:19:41	31.40	0.27	20.44	5.44	OFF
03/08/2025	15:20:23	32.40	0.23	20.15	4.66	OFF
03/08/2025	15:21:08	33.80	0.24	20.05	4.88	OFF
03/08/2025	15:21:30	34.40	0.23	19.93	4.58	OFF
03/08/2025	15:22:02	35.60	0.24	19.78	4.67	OFF
03/08/2025	15:22:12	36.10	0.22	19.73	4.35	OFF
03/08/2025	15:22:42	37.60	0.23	19.66	4.48	OFF
03/08/2025	15:23:07	38.50	0.22	19.53	4.38	OFF
03/08/2025	15:23:35	39.60	0.22	18.36	4.01	OFF
03/08/2025	15:23:48	40.10	0.21	18.36	3.83	ON
03/08/2025	15:24:19	40.20	0.22	19.01	4.24	ON
03/08/2025	15:24:28	40.40	0.22	18.30	4.08	ON
03/08/2025	15:25:32	39.60	0.21	19.86	4.26	ON
03/08/2025	15:25:43	39.60	0.24	20.26	4.91	ON
03/08/2025	15:25:53	39.10	0.18	19.76	3.58	ON
03/08/2025	15:26:24	38.20	0.24	20.24	4.89	ON
03/08/2025	15:26:43	37.00	0.24	20.58	4.85	ON
03/08/2025	15:27:16	35.80	0.24	20.36	4.81	ON
03/08/2025	15:27:36	35.80	0.24	20.46	4.96	ON
03/08/2025	15:27:48	34.90	0.24	20.73	4.96	OFF
03/08/2025	15:28:51	34.00	0.24	20.22	4.87	OFF
03/08/2025	15:29:45	34.10	0.25	19.81	4.95	OFF
03/08/2025	15:30:48	33.90	0.26	21.28	5.60	OFF
03/08/2025	15:31:08	33.40	0.25	21.74	5.46	OFF
03/08/2025	15:32:25	32.70	0.24	20.89	5.09	OFF
03/08/2025	15:33:54	33.20	0.24	20.68	4.94	OFF
03/08/2025	15:34:58	33.40	0.22	19.97	4.48	OFF
03/08/2025	15:36:02	34.00	0.22	20.07	4.47	OFF
03/08/2025	15:37:55	34.60	0.26	19.80	5.24	OFF
03/08/2025	15:39:43	35.90	0.24	20.04	4.87	OFF
03/08/2025	15:40:13	35.70	0.22	20.07	4.35	OFF
03/08/2025	15:41:47	35.90	0.25	20.54	5.18	OFF
03/08/2025	15:42:08	36.00	0.23	20.11	4.60	OFF
03/08/2025	15:43:04	37.30	0.26	20.09	5.23	OFF
Average		33.97	0.30	20.05	6.61	

Table 2. System testing data without cooling

Data	Time	Temperature (°C)	Current (A)	Voltage (V)	Power (W)
03/08/2025	15:19:14	31.90	0.24	20.44	4.92
03/08/2025	15:19:43	32.40	0.26	20.35	5.25
03/08/2025	15:20:26	33.40	0.24	20.35	4.81
03/08/2025	15:21:08	34.60	0.23	20.09	4.52
03/08/2025	15:21:30	35.10	0.24	19.95	4.80
03/08/2025	15:22:01	35.80	0.23	19.92	4.54
03/08/2025	15:22:13	36.10	0.23	20.03	4.60
03/08/2025	15:22:46	37.60	0.25	19.81	4.86
03/08/2025	15:23:05	37.80	0.22	19.50	4.29
03/08/2025	15:23:39	38.40	0.22	18.79	4.15
03/08/2025	15:23:58	39.60	0.22	19.23	4.26
03/08/2025	15:24:08	40.30	0.21	18.66	3.90
03/08/2025	15:24:28	40.20	0.22	19.09	4.26
03/08/2025	15:25:08	40.20	0.22	18.51	4.03
03/08/2025	15:25:32	40.30	0.24	19.95	4.80
03/08/2025	15:25:53	40.30	0.23	18.86	4.36
03/08/2025	15:26:22	40.40	0.23	18.86	4.36
03/08/2025	15:26:43	40.40	0.22	19.60	4.35
03/08/2025	15:27:16	40.40	0.22	19.60	4.35
03/08/2025	15:27:36	40.40	0.22	19.23	4.26
03/08/2025	15:27:48	40.50	0.22	19.22	4.23
03/08/2025	15:28:43	40.40	0.22	19.37	4.33
03/08/2025	15:29:45	40.50	0.20	19.54	3.90
03/08/2025	15:30:48	40.50	0.19	18.93	3.52
03/08/2025	15:31:08	40.50	0.21	19.25	4.11
03/08/2025	15:32:23	40.70	0.21	19.30	4.09
03/08/2025	15:33:59	41.60	0.23	18.86	4.36
03/08/2025	15:35:00	42.00	0.22	18.53	4.08
03/08/2025	15:36:04	42.00	0.22	18.74	4.15
03/08/2025	15:37:50	41.90	0.22	19.23	4.21
03/08/2025	15:39:43	42.50	0.21	18.86	3.96
03/08/2025	15:40:13	42.70	0.21	18.81	3.98
03/08/2025	15:41:47	42.80	0.22	19.57	4.25
03/08/2025	15:42:59	43.00	0.22	19.37	4.33
03/08/2025	15:43:04	42.90	0.21	19.34	4.09
Average		39.43	0.22	19.36	4.32

In this test using solar panels with a capacity of 10 WP, with data obtained in the form of date, time, temperature, current, voltage and power and pump status for solar panels with a cooling system. Comparison of solar panel output with cooling system and without cooling system can be seen in Table 3.

Table 3. Comparison of Solar Panel Output

Solar Panel	Voltage (V)	Current (A)	Power (W)	Temperature (°C)
With Cooler	20.04	0.23	4.6	35.86
Without Cooling	19.36	0.22	4.25	39.43

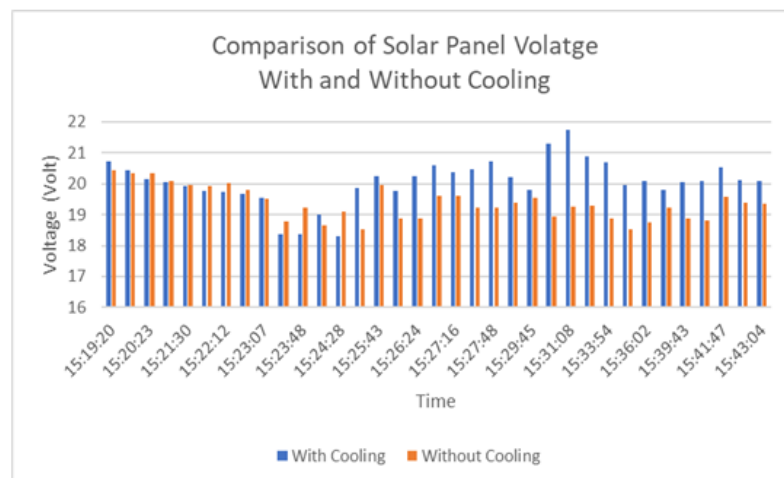
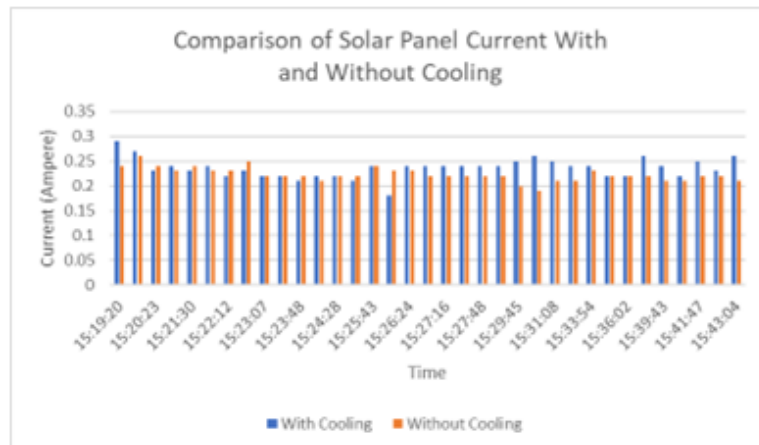
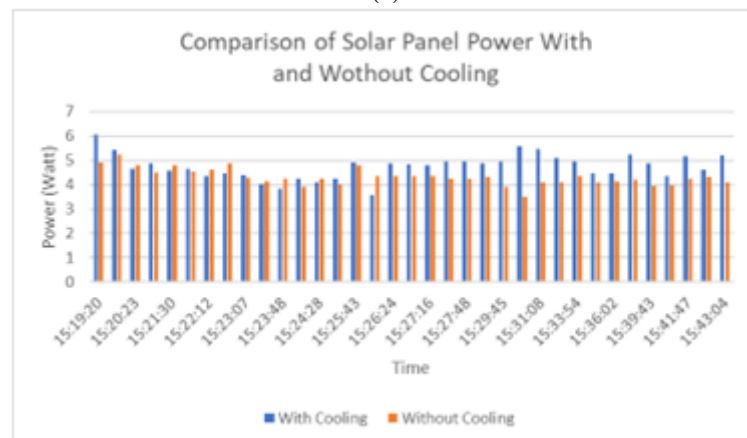


Figure 7. Comparison graph of solar panel output voltage

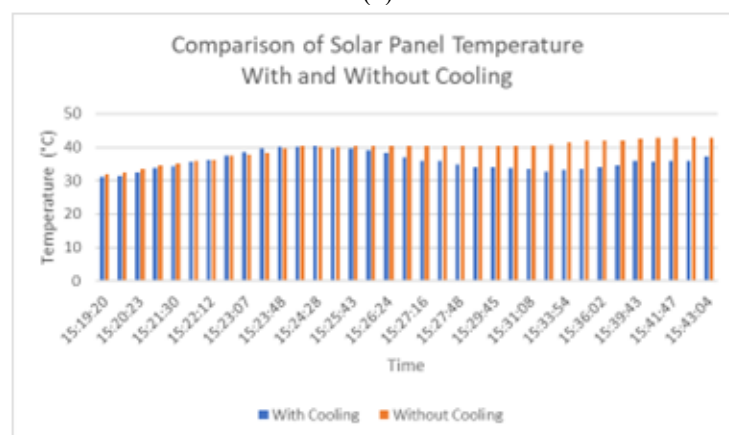
Based on the data obtained, it is known that the power generated by solar panels with a cooling system is 4.6 Watt with an efficiency of 5.6 % and without cooling is 4.25 Watt with an efficiency of 5.18%. The cooling system implemented was able to reduce the panel temperature by 3.57°C, which contributed to an increase in output power of 0.35 W, with a change in power for each increase or decrease in temperature of about 0.1 W/°C. This increases the panel efficiency by 8.1 % so that the cooling system is considered effective in maintaining the performance and increasing the output power of the solar panel. The following is a comparison graph of voltage, current, power and temperature of solar panels using cooling and without cooling based on the data that has been obtained.



(a)



(b)



(c)

Figure 8. Experimental results. a) Solar panel output current, b) Solar panel output power, b) Solar panel temperature

4. CONCLUSION

Based on the tests conducted, the cooling system on solar panels is able to effectively maintain and increase the output power of solar panels by controlling the panel temperature to stay below 40°C. Based on tests conducted for ± 20 minutes with a sample of 35 data each, the cooling system applied is able to effectively reduce the temperature of the solar panel by 3.57°C, which contributes to an increase in output power of 0.35 W, with a change in power for each increase or decrease in temperature of about 0.1 W /°C.

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