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Research Article

Enhancement of Solar Panel Efficiency by Comparative Analysis of Cooling Systems Utilizing Water Flow, Air Flow, and No Cooling

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Abstract

This paper presents the results of a study on increasing the efficiency of solar panels with a comparative analysis of cooling systems utilizing air flow, air and without cooling. This study presents a comparative analysis of cooling techniques to improve solar panel efficiency under tropical climate conditions, offering insight into low-cost thermal regulation methods to mitigate panel overheating. The method with cooling flow is used to absorb heat generated by the PV module. This study was designed simply and effectively, tested in outdoor conditions. The rear surface of the PV panel was flowed with a fluid that was in direct contact. The results showed that solar panels with air cooling systems were relatively more effective compared to other cooling systems, namely being able to increase output power by 36.50 watts and efficiency by 12.7%, compared to air cooling systems with output power of 34.56 watts and efficiency of 11.12%, while for solar panels without cooling the output power was 31.01 watts and efficiency of 10.56%.

Keywords: *PV panel Cooling, Active cooling, Energy efficiency*

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INTRODUCTION

Solar energy is one of the most potential renewable energy sources to replace the increasingly depleting fossil fuel sources [1]. With environmentally friendly, unlimited, and available characteristics in almost all regions of the world [2], solar energy is the main choice in global efforts to reduce greenhouse gas emissions and achieve desired energy [3]. Solar panels or photovoltaics (PV) are a technology commonly used to convert solar energy into electricity [4]-[5]. However, the performance of solar panels is greatly influenced by environmental conditions that are too hot due to high exposure to sunlight [6]-[7]. High solar cell temperatures can cause degradation of photovoltaic cells, efficiency lower energy conversion [8]-[9].

The efficiency of solar panels decreases as the surface temperature of the panel increases [10]. High temperatures cause electrical resistance to increase [11], which ultimately reduces the electrical power generated [12]. Therefore, one of the main challenges in increasing the efficiency of solar panels is controlling their operational temperature [13]-[14]. Various methods have been developed to overcome this problem, including active and passive cooling systems [15]-[16]. Among these methods, cooling using water flow and air flow is the most widely studied and applied technique due to its ease of implementation and effectiveness [17].

The water flow cooling method, utilizes the high thermal conductivity of water to absorb and release heat from the panel surface [17]. Meanwhile, air flow cooling uses air movement to remove heat through the convection process [18]. Although both of these methods have shown potential in increasing the efficiency of solar panels, their effectiveness can vary depending on environmental conditions and the design of the cooling system [19]. In addition, it is necessary to evaluate the performance of solar panels operated without cooling as a control to understand the direct effect of temperature on efficiency [18].

This study aims to optimize the efficiency of solar panels through a comparison of three systems, namely a cooling system using water flow, air flow, and without cooling. This study will provide insight into the advantages and limitations of each method, as well as help determine the most effective cooling solution in various environmental conditions. Thus, the results of this study are expected to contribute to the development of more efficient and sustainable solar energy technology.

METHODS AND ANALYSIS

This study uses a quantitative experimental approach to test and compare the performance of solar panels with three different cooling treatments: without cooling, with cooling using air flow, and with cooling using water flow. Before measurements are taken, terlebih dahulu The calibration was conducted by placing both the thermocouples (Type-K) and the thermometer in a controlled temperature bath, and comparing the readings to ensure accuracy within ±0.5°C.

The study was conducted using an experimental method based on controlled treatment, where each solar panel was tested under the same conditions to ensure the uniformity of environmental influences on the measurement results. Thus, the application of a solar panel cooling system has been proven [20], reducing the temperature and increasing the performance of solar panels [21], at the stage of implementing the experiment, measurements of temperature, solar radiation, and electrical power were carried out on each air-cooled, water-cooled and uncooled solar panel operating for one full day (from 09.00 to 16.00). An illustration of the research method can be seen in Figure 1.

Instrument Calibration Procedure

In this study, instrument calibration was carried out to ensure the accuracy and consistency of temperature, voltage, current, and solar radiation intensity measurement data. Step calibration is crucial before carrying out cooling system testing on solar panels, considering that the measurement results are the basis for analyzing the efficiency of each system.

The instruments used in this study include: temperature sensor (K-type thermocouple), digital multimeter to measure voltage and current, pyranometer for measuring solar radiation intensity, and flow meter (for air and air flow systems). The calculation procedure is carried out as follows:

Temperature sensor calibration

The temperature sensor is calibrated using a dry block calibrator at several reference temperature points (25°C, 50°C, and 75°C). The sensor reading results are compared with the reference temperature from the calibrator. If a deviation of more than ±1°C is found, adjustments or placement of the sensor are made.

Multimeter calibration

The digital multimeter is calibrated using a standard voltage and current source from a digital electrical calibrator (Fluke Calibrator). The reference voltage is set at 5 V and 12 V, while the reference current is set at 0.5 A and 1 A. The reading results are compared with the reference value, and the deviation is recorded. The multimeter is declared suitable for use if the deviation does not exceed 1% of the reference value.

Pyranometer calibration

The pyranometer is calibrated by comparing its readings to a certified pyranometer standard under direct sunlight conditions. Testing is carried out during the day at the same time and in the same location. If there is a difference of more than 5% to the reference tool, then a correction value is added during data analysis.

Flow Meter Calibration

The flow meter is calibrated using the gravimetric calibration method, which is to compare the flow indicated by the flow meter with the actual volume of liquid/air contained in a certain period of time. Calibration was performed at several flow rates (1 L/min, 2 L/min) and the deviation was calculated.

This research is experimental research which aims to investigate the possible influence of independent variables (pyrolysis temperature variations) on dependent variations (char mass, char volume, tar mass, tar volume and heating value) in the experimental group.

The biomass of plastic and durian skin is cut into small pieces of 1cm^2. The biomass of brem waste, plastic and durian skin is dried in the sun to reduce the water content. After drying, it is put in a closed place. Before testing, the biomass is dried for 120-180 minutes at a temperature of 383 – 398K in a drying machine until the water content is <2%. After drying, the biomass sample is put into the machine for pyrolysis. This process is carried out on all biomass and at each temperature variation.

Device design

The design of the tool is the most crucial stage in preparing the manufacture of data collection tools and preparing the provision of tools and materials used to support the implementation of data collection in the field. Thus, the variable data obtained is in accordance with the objectives of the study. This design certainly aims to reduce errors in the final design of the test tool before the test is continued. Before making the tool, the tool is first designed to determine the dimensions and calculate the number of tools and materials needed during the design process. The tools used in this study are 50 WP solar panels, thermocouples, solar power meters, flow meters and blowers.

Solar Panel Cooling System Experimental Design

This study compares the efficiency of three cooling conditions on solar panels, namely cooling with water flow, cooling with air flow, and without cooling. Each system is designed separately but uses identical panel types and measuring instruments to maintain data consistency.

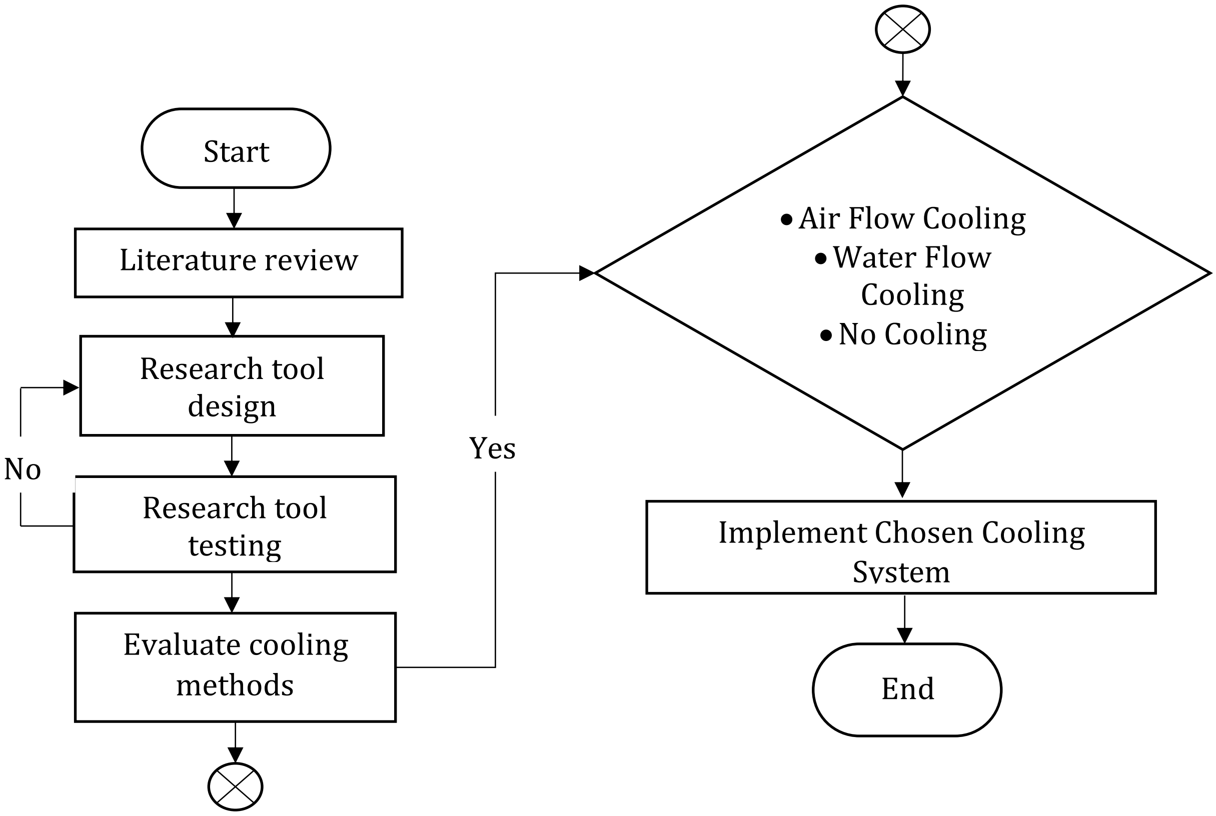

Figure 1. Reseacrh Implementation Scheme

(a) Water Flow Cooling (b) Air Flow Cooling (c) No Cooling

Figure 2. Water-cooled, air-cooled and uncooled PV modules

Figure 2 shows the physical configuration of the three cooling systems: Figure 2 (a) shows a solar panel equipped with a Water Flow Cooling system, where water is flowed through the back surface of the panel using a small pump and flexible water distribution channels. The purpose of this system is to absorb excess heat generated while the panel is operating under direct sunlight. Figure 2 (b) shows the Air Flow Cooling configuration, where a fan is installed to generate air flow directed to the bottom surface of the solar panel. This system aims to lower the panel temperature by utilizing forced convection from the air. Figure 2 (c) shows a solar panel in a condition without a cooling system as a comparison (control). In this test, the panel was allowed to operate naturally without the help of external cooling.

These images also show the placement of measuring instruments such as digital multimeters and temperature sensors, which are used to record panel performance data under actual field conditions. All systems were tested under relatively similar solar radiation conditions to ensure the validity of the comparison of thermal efficiency and electrical power output.

The test was conducted with the aim of determining the characteristics of the output power and efficiency produced by solar panels using water, air and uncooled cooling systems with direct sunlight. The equations used are;

$$\eta = \frac{P_{out}}{E\ .\ A} \times 100\ \% \quad (1)$$

The efficiency (η) of PV is obtained by dividing the output power (Pout) by the solar irradiation (E) and the PV surface area (A) [7], according to equation (1). Meanwhile, the output power of the PV panel is obtained by multiplying the current (I) and voltage (V) [5], which can be calculated using equation (2).

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

RESULTS AND DISCUSSIONS

Experimental

The results of the experimental test will show a graph of the increase and decrease in solar panel performance. To produce a constant calculation, the test result data will be processed into an average value of each observed variable. This test refers to research conducted by Mohamad Abou Akrouch, et al. [9] which states that passive cooling by spraying water on the surface of solar panels can increase PV efficiency. Therefore, this observation will be carried out at 09.00-16.00 minutes, with a time interval of 30 minutes with the provision that the data collection of the solar radiation intensity variable must be >800 W/m2. The flow rates for both water and air were selected based on prior literature and practical cooling system capabilities. For water cooling, a flow rate of 0.1L/s

Table 1. Test results of water-cooled, air-cooled and uncooled solar cells

Time	Water Cooled		Air Cooled		No Colling	
	Power (W)	Efficiency (%)	Power (W)	Efficiency (%)	Power (W)	Efficiency (%)
9.00	22,48	11,3	20,70	10,44	18,42	9,29
9.30	22,91	11,1	22,04	10,71	20,59	10,01
10.00	26,84	11,0	24,33	9,93	22,55	9,20
10.30	29,16	11,8	27,30	11,06	24,85	10,07
11.00	32,09	12,6	30,10	11,85	27,41	10,79
11.30	33,87	12,7	32,19	12,09	31,01	11,64
12.00	36,50	11,7	34,56	11,12	32,81	10,56
12.30	35,31	11,4	34,28	11,09	32,68	10,57
13.00	34,56	11,6	32,68	10,93	31,76	10,62
13.30	32,19	11,1	31,82	11,02	30,34	10,51
14.00	30,46	11,2	28,99	10,70	26,60	9,82
14.30	28,27	10,7	26,55	10,08	24,71	9,38
15.00	24,74	9,7	22,84	8,97	21,16	8,31
15.30	22,11	9,2	20,63	8,57	19,28	8,01
16.00	15,49	7,7	14,15	7,00	14,58	7,21

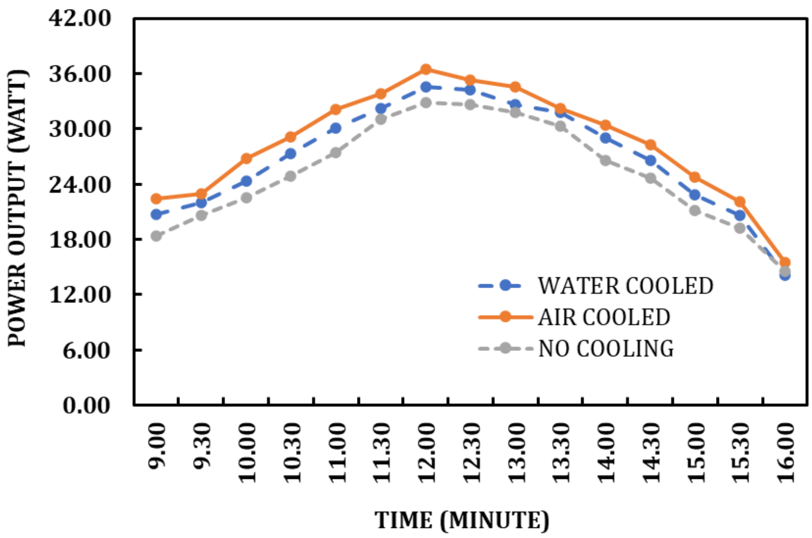

Figure 3. PV Output Power

was used, which ensures a laminar flow across the panel surface while conserving water. For air cooling, a fan providing 2.5 m/s airflow was applied, simulating moderate wind conditions. Both values were selected to compare passive and active cooling in a realistic, energy-efficient context.

The observation data in Table 1 are processed into an average, which is then calculated to determine the value of the test variable. All experiments have met the requirements of solar radiation intensity at the maximum point used as a reference value in the calculation to assess the effect of test variables on the performance of solar panels at 12:00 minutes.

Effect of Cooling and Non-Cooling Systems on PV Output Power

The graph in Figure 3 shows the output power versus time under three different cooling conditions, water-cooled, air-cooled and uncooled. The increase in power from the beginning of the measurement at 9:00 minutes, where the initial power for the water-cooled, air-cooled and uncooled systems were 22.48 W, 20.70 W and 18.42 W respectively. Power continued to increase in accordance with the increase in solar radiation intensity reaching a peak at around 12:30, with maximum power in the water-cooled system of 36.50 W, air-cooled 34.56 W, while the uncooled solar panel was 32.81 W. After reaching its peak, the power decreased gradually until 16:00, where the power dropped to 15.49 W for the water-cooled, 14.15 W for the air-cooled, and 14.58 W uncooled systems. Of the three systems, water cooling produces the highest power almost all the time, consistent with previous research [22], for the air-cooled system it is slightly closer with a difference of 1.94 W, while the uncooled solar panel shows the lowest power. This pattern shows that the cooling system plays an important role in maintaining power, where water cooling is more active than air cooling, while without cooling, power tends to decrease faster. Thus, a better cooling system can help maintain power stability over a longer period of time.

Effect of cooling system on PV Efficiency

The graph in Figure 4 shows the change in efficiency over time with three different conditions, namely water-cooled, air-cooled, and uncooled. In general, efficiency increases from 9:00 minutes to a peak at around 11:30 minutes to 12:30 minutes, where the water-cooled system shows the highest efficiency, followed by the air-cooled system, while uncooled has the lowest efficiency. After reaching the peak, efficiency begins to decrease along with the intensity of solar radiation until 16:00 minutes. At the beginning of the measurement at around 9:00 minutes, the efficiency for the water-cooled system is slightly higher than the others, with a value of around 10%, while the air-cooled and uncooled systems are slightly lower. Along with

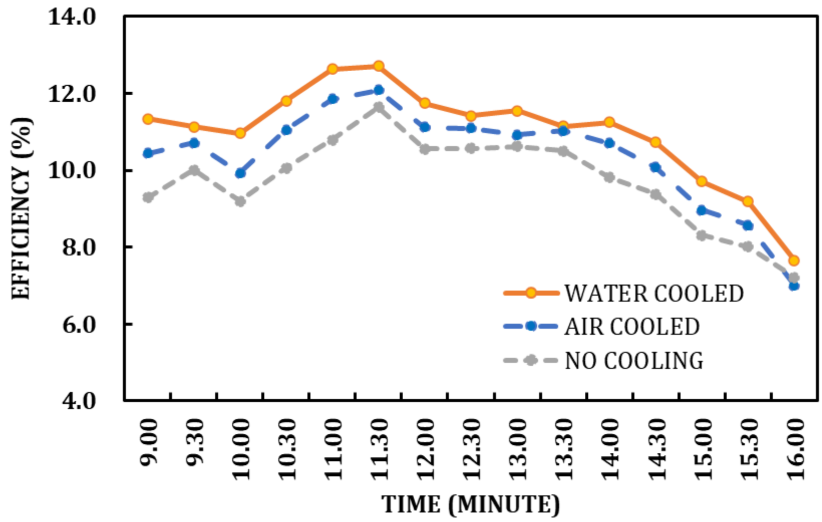

Figure 4. PV Efficiency

the increase in the intensity of sunlight radiation, the increase in efficiency values continues to occur to a maximum value of 12-13 % for the water-cooled system, 11-12 % air-cooled, and 10 % uncooled.

CONCLUSIONS

The results of the study showed that solar panels with water cooling systems are relatively more effective compared to other cooling systems, increasing output power by 36.50 watts and efficiency of 12.7 %, compared to air cooling systems with output power of 34.56 watts and efficiency of 11.12 %, while for solar panels without cooling the output power is 31.01 watts and efficiency of 10.56 %.

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DECLARATION OF CONFLICTING INTERESTS

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article for our colleagues

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