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Effect of Pulsed-Spray Time Variations with Water Coolant in Cooling Media on Solar Panel Efficiency and Temperature

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Abstract

Solar panel technology enables the conversion of sunlight into electrical energy. However, some problems can arise with the performance of solar panels, for example, increasing the temperature of the solar panels beyond their working limits. Increasing temperatures will reduce the performance of solar panels. So, it is essential to maintain the temperature of the solar panels so that their performance remains optimal. This research was conducted to determine the effect of delayed timing of the back and front surfaces of spray cooling on average temperature, output power, and solar panel energy optimization. This experimental test can reduce the temperature of solar panels at a spray delay time of 10 minutes to 58.95°C, at a spray delay time of 20 minutes to 70.78°C, and at a spray delay time of 30 minutes to 78.63 °C. The cooling method is carried out for 1 minute with varying spray delay times of 10, 20, and 30 min. Through this test, the total energy value is also obtained. Suppose the spray delay time is 10, 20 and 30 min, respectively, 5.60 x 10^{-3} kWh (20150.78 Joules), 5.27 x 10^{-3} kWh (1897.,11 Joules) and 5.11 x 10^{-3} kWh (18383.68 Joules). The conclusion from the research that has been carried out is that the most optimal delay time is a delay time of 10 minutes with an average temperature of 58.95°C, and the best energy optimization is with a total energy of 20150.78 Joules or 5.27 x 10^{-3} kWh.

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1. Introduction

Most electrical energy in Indonesia is produced from fossil fuels in Steam Power Plants (PLTU). The process of generating electrical energy from PLTU produces ash-containing materials that are harmful to the environment (Rofandi, 2022). The use of renewable energy must be maximized to reduce the dependence on electrical energy sourced from the PLTUs. Solar power from photovoltaics is an environment-friendly technology commonly used worldwide (Homadi, Hall, & Whitman, 2020).

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Solar panels are solar cells that convert the sun's radiation into electrical energy through photovoltaics (Ahmad et al., 2021).

Photovoltaic Solar panel technology with photovoltaics has weaknesses, such as decreasing operation as the operating temperature increases, so that the energy conversion becomes low (Skoplaki & Palyvos, 2009). In other studies on photovoltaics using water-cooling media, it is estimated that every 1^{0C} increase in temperature will reduce the efficiency of photovoltaic performance by 0.4 - 0.5% (Sudhakar et al., 2021).

Several studies have been conducted on cooling with various media to overcome the shortcomings of photovoltaics related to the operating temperature. Photovoltaics can be cooled using passive, air-, and liquid-cooling methods (Siecker et al., 2017). Experimental studies were conducted on cooling by spraying water on the PV panels, which was used to reduce the maximum permitted temperature of 45^{0}C to an average operating temperature of 35^{0}C. This method uses hot and dry areas (Moharram et al. 2013). Another study attempted a cooling method by spraying water on the back side of PV panels. As a result, the PV panel temperature drops by approximately 20%, thereby increasing panel efficiency by 9% (Bahaidarah et al., 2013). The cooling method for water spraying was developed using double-sided spraying (front and back of the PV panel). This method can increase the electrical power output by 7.7%, panel electrical efficiency by 5.9%, and reduce the PV panel temperature from 54 to 24^{0}C (Nižetić et al., 2016). Laboratory-scale experimental research has been conducted to determine the cause of intermittent cooling or cooling with a specific time delay in cooling PV panels. The water flow rate was set at different speeds: 3 liters/minute, 5.3 liters/minute, and 6.2 liters/minute. These three experiments increased the total electrical energy by approximately 18% compared with that without the PV panel cooling method (Saxena et al., 2018).

Recent research has proposed a PV panel cooling solution with cooling on both sides of the panel surface. Hadipour et al. compared steady and pulsed spray methods for PV cooling. The maximum power outputs were 33.3% and 27.7%, respectively. However, the costs incurred for the pulsed-spray cooling method are 46.5% lower than those for the steady-spray method (Hadipour, Zargarabadi, & Rashidi, 2021). Bhakre et al. conducted experiments on the effect of cooling on a PV system on the front, rear, and combined surfaces (front and rear). This experiment significantly reduced the temperature of the PV panels by 22-27^{0}C, cleaning the surface of the PV panels from dust that blocks sunlight. A reduction in PV panel temperatures of 5-6^{0}C occurred when water flowed through the front surface of the PV panels (Bhakre, Sawarkar, & Kalamkar, 2021). (Agyekum et al., 2021). experimented with a simultaneous double-cooling method on the front with water and back with a cotton mesh that absorbs water from the front of the panel. This experiment reduced the temperature by 23.55^{0}C and increased the power output by 30.3%. It has an average efficiency of 14.36% compared with 12.83% without a cooling method (Agyekum et al., 2021).

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Previous research on methods for cooling PV panels using water media, either by spraying the front, back, or a combination of both, produced better energy power and efficiency than wind cooling media. The speed and timing of water spraying also affect the power and efficiency of the PV panels. However, a new problem arises: The constant use of water in the PV cooling method creates a continuous dependence on water as the cooling medium (Hadipour et al., 2021). Water loss must be minimized by using the water collected in containers and adjusting the water pump capacity (water flow rate). Therefore, water loss is obtained only from water evaporation when cooling occurs on the surface of the PV panel (Bhakre et al., 2021). This method is believed to increase the service life of PV panels, efficiency, and total electrical power produced (Sharma et al., 2018).

Research on heat transfer using a water coolant radiator can effectively reduce the engine temperature. The composition of the cooling media with a mixture of 50% water and 50% radiator coolant was compared to other variations in engine cooling (Hadi & Muttaqin, 2014). Ethylene Glycol (EG), a radiator water coolant, is traditionally used to cool car radiators. A mixture of pure water and EG at a 2-6 liters/minute flow rate improves heat transfer by approximately 40% (Peyghambarzadeh et al., 2011). Other research states that a mixture of water, EG, and Al_2O_3 nanofluid can increase the heat transfer by 30% (Subhedar et al., 2018).

Based on previous research regarding the cooling methods for PV panels and a mixture of water with EG, a mixture of water coolants containing EG and water is interesting for implementing PV panel cooling methods. In this study, a water coolant was used to compare the varying pulsed spray times on the front and back surfaces. Hopefully, this research can provide information regarding variations in pulsed spray time and temperature on PV panels, efficiency, and total energy produced. Therefore, PV panels can produce a high efficiency and total energy while maintaining a constant temperature. In addition, the mixture of water and EG is expected to reduce water loss on the PV panel surface owing to water evaporation.

2. Materials and Methods

2.1 Materials and Tools

The equipment used in this research included a temperature sensor or thermocouple to measure the temperature on the panel, an avometer to measure the Electric Current from the solar panel, a laptop, a lux meter or solar meter to measure light, a data logger to input data, five K-type thermocoples to measure the average front and back surface temperatures, a cover box to avoid the influence of air from the outside, and a DC water pump with specifications of 12 V, 3.5 A, 4 LPM, 0.6 Mpa. The materials used in this research were 100 WP solar panels, 500-watt floodlights as a sunlight simulator, water coolers, 0.8 mm nozzles, 5/16 threaded hoses, and 6 × 4 mm PU hoses. The solar panel design is illustrated in Figure 1, and the detailed positions of the solar simulator, thermocouples, and spray nozzles are shown in Figure 2.

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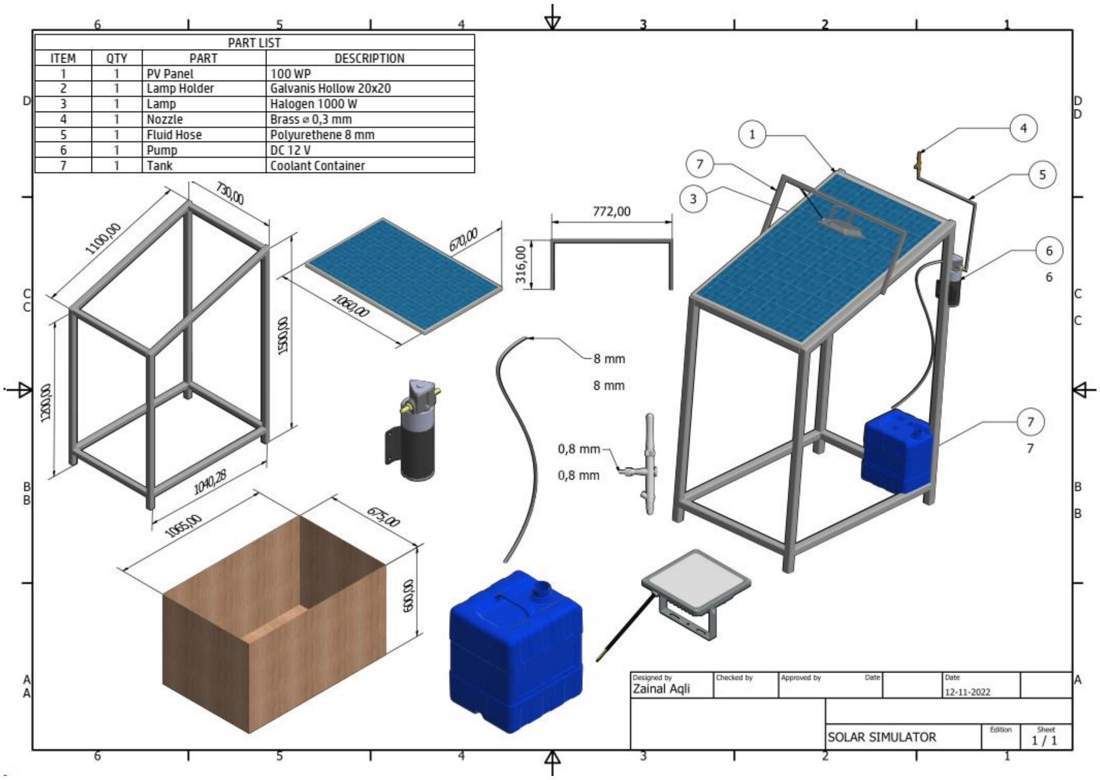

Figure 1. Solar panel installation.

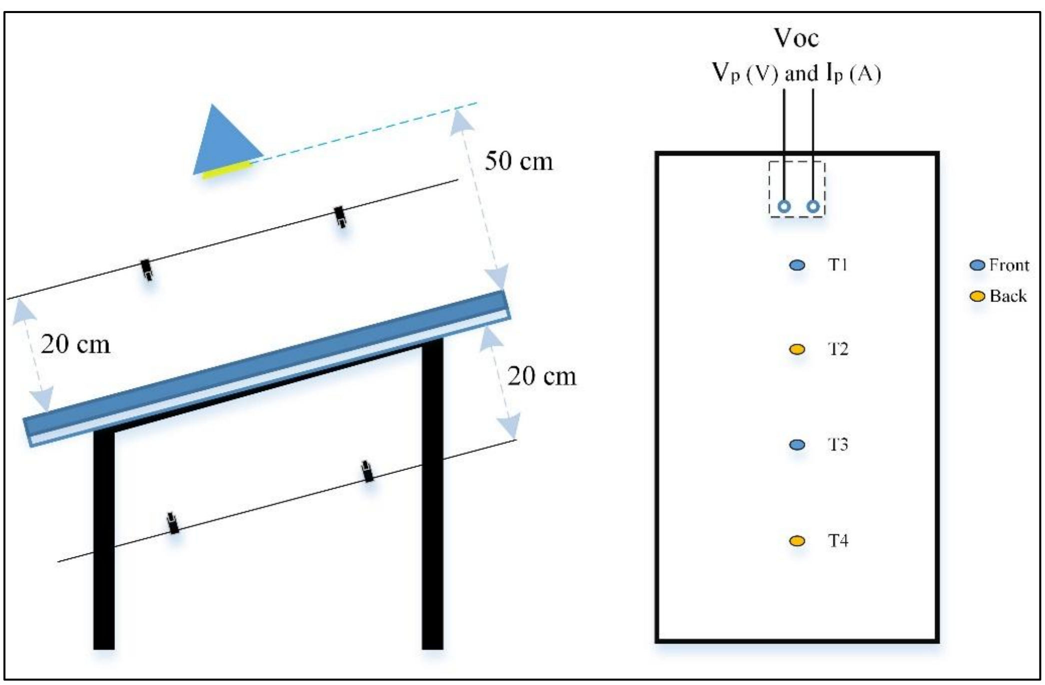

Figure 2. Sunlight simulator, spray nozzles, and termocouples position.

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2.2 Research Procedure

The research procedure used in this study is illustrated in Figure 3. An experimental study was conducted to determine the effect of variations in the pulsed spray time with water coolant on the cooling process on the front and back surfaces of PV panels.

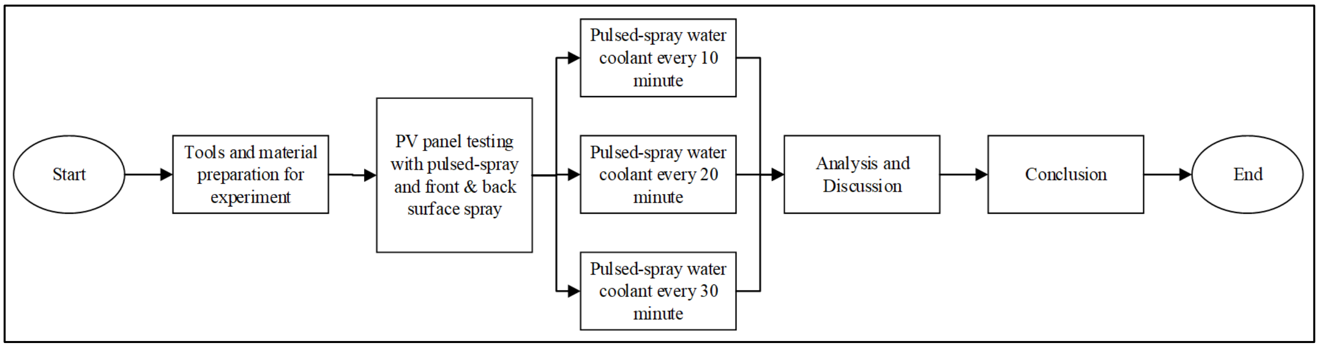

Figure 3. Research procedure for cooling PV panels with pulsed-spray water coolant.

Observations were made by preparing necessary tools and materials. Next, the nozzle for the water coolant mixture pump was set to a pressure of 0.6 Mpa and a liquid flow rate of approximately 4 L/min, and the pump was not energized by the PV panel. Next, a ratio of 30:70, that is, 30% water and 70% water coolant, was used for the composition of the mixture of water and water coolant. The spray times were 10 min, 20 min, and 30 min. The spray time was measured on the front and back surfaces of the panels. The open-circuit voltage was measured using a data logger and digital avometer every minute within one hours.

The observation process was conducted for 60 min, and the total heat energy (J), PV panel temperature (K), and total energy (W) were recorded. These parameters were recorded using a data logger and stored on a micro SD memory card. Next, the data were analyzed to determine which water coolant produced more total energy, better efficiency, and maximum temperature reduction.

2.3 Observation Parameters

The parameters used in this research were the distance between the solar simulator and solar panels of 50 cm or radiation of approximately 700 W/m2. The distance between the nozzle and the solar panel was 40 cm, with a slope of 15^0, and the distance between the nozzle below the panel was 30 cm, with a slope of 15^0. After the solar simulator was turned on, data on the panel temperature (Ts), liquid outlet temperature (To), open-circuit voltage (Vp), and short-circuit current (Ip) without and with cooling treatment were obtained. The cooling treatment was carried out by setting the water spray cooling system for 5 min with spray delay times of 10 min, 20 min, and 30 min. A Jumbo radiator coolant containing Ethylene Glycol was used.

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2.4 PV Panel Performance and Enegy Calculation Methods

For the calculations, the solar panel performance was measured based on solar panel efficiency. The PV panel efficiency is an indicator of the PV panel performance. Efficiency is obtained by comparing the amount of electrical energy produced by the manufacturer's electrical energy claims (Asrori & Yudiyanto, 2019). PV panel efficiency can be defined using Equation 1.

$$\eta = \frac{V_p \; x \; I_p \; x \; FF}{E \; x \; A_p} \; x \; 100\% \quad (1)$$

Where η: PV panel efficiency, V_p: open circuit voltage (V), I_p: short circuit current (A), E: intensity of solar radiation (W/m^2), A_p: PV panel surface area (m^2). Fill Factor (FF).

The fill factor (FF) is a critical metric that signifies the efficiency of photovoltaic (PV) systems in converting solar energy into electrical power. According to research, the FF for commercial PV modules generally ranges between 70% and 85%, with a value above 70% often regarded as efficient for practical applications (Jaber et al., 2022; Yadav et al., 2023). In this study, an FF of 70% was adopted as a benchmark, which is consistent with the baseline efficiency of standard PV modules.

Because this research uses a solar simulator from a 500 W lamp (Soliman et al., 2019) instead of sunlight, a constant is needed to calculate the intensity of light radiation from the lamp (Cahyono, 2020). Therefore, it is necessary to use Equation 2.

$$G = \frac{L_v}{K} \quad (2)$$

Where G: the radiation intensity of light rays from the lamp (W/m^2), L_v: Light intensity (lumen/m^2), K: light efficacy (lumen/W).

The heat energy released from the process of spraying cooling media on the surface of the PV panels (Armendáriz-Ontiveros et al., 2022) can be calculated using Equations 3, 4, and 5, as follows:

$$\mathrm{q} = \mathrm{Q}.\, \rho_c . \mathrm{C}_{wp} \, (\mathrm{T}_{out} - \mathrm{T}_{in}) \quad (3)$$

Where q: heat energy, Q: water coolant cooling discharge (m^3/s), C_{wp}: water cooling calorification capacity (kJ/kg K), T_{in}: initial water coolant temperature (^{0}C), T_{out}: final water coolant temperature (^{0}C)

$$\Delta T_{Lm} = \frac{\mathrm{T}_{out} - \mathrm{T}_{in}}{\ln\left(\frac{\mathrm{T}_p - \mathrm{T}_{in}}{\mathrm{T}_p - \mathrm{T}_{out}}\right)} \quad (4)$$

Where ΔT_{Lm}: average temperature of panels and water coolant (^{0}C), T_p: panel temperature (^{0}C)

$$\mathrm{U} = \frac{q}{A_p \Delta T_{Lm}} \quad (5)$$

Where U: heat transfer coefficient, A_p: panel surface area (m^2)

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3 Results and Discussion

This test was performed by taking the temperature and output data from the solar panel every minute for 30 min. Based on these tests, the relationship between the temperature and the output power of the solar panels was obtained (see Table 1).

Table 1. The correlation between temperature and output power on solar panels with a spray timing delay of 30 minutes.

No	Panel Temperature (°C)	Open Circuit Voltage (V)	Short Circuit Current (A)	Energy Output (W)
1	37,26	21,01	0,413	6,08
2	41,48	20,71	0,411	5,96
3	46,02	20,38	0,409	5,84
4	50,7	20,1	0,406	5,71
5	55,15	19,83	0,403	5,59
6	59,16	19,56	0,401	5,49
7	62,64	19,32	0,399	5,40
8	65,69	19,08	0,398	5,31
9	68,43	18,89	0,396	5,24
10	70,81	18,72	0,394	5,17
11	72,66	18,58	0,393	5,11
12	74,38	18,46	0,392	5,07
13	75,75	18,34	0,391	5,02
14	77,43	18,23	0,391	4,99
15	81,59	18,15	0,39	4,96
16	84,85	18,09	0,389	4,93
17	86,37	18,03	0,389	4,91
18	87,4	17,96	0,389	4,89
19	88,07	17,91	0,388	4,87
20	88,72	17,86	0,388	4,85
21	89,11	17,81	0,388	4,84
22	89,71	17,8	0,388	4,84
23	90,36	17,77	0,387	4,82
24	90,84	17,74	0,387	4,81
25	89,66	17,72	0,387	4,80
26	90,74	17,71	0,387	4,80
27	91,35	17,68	0,386	4,77
28	91,68	17,66	0,386	4,77
29	91,98	17,64	0,386	4,77
30	92,18	17,65	0,386	4,77

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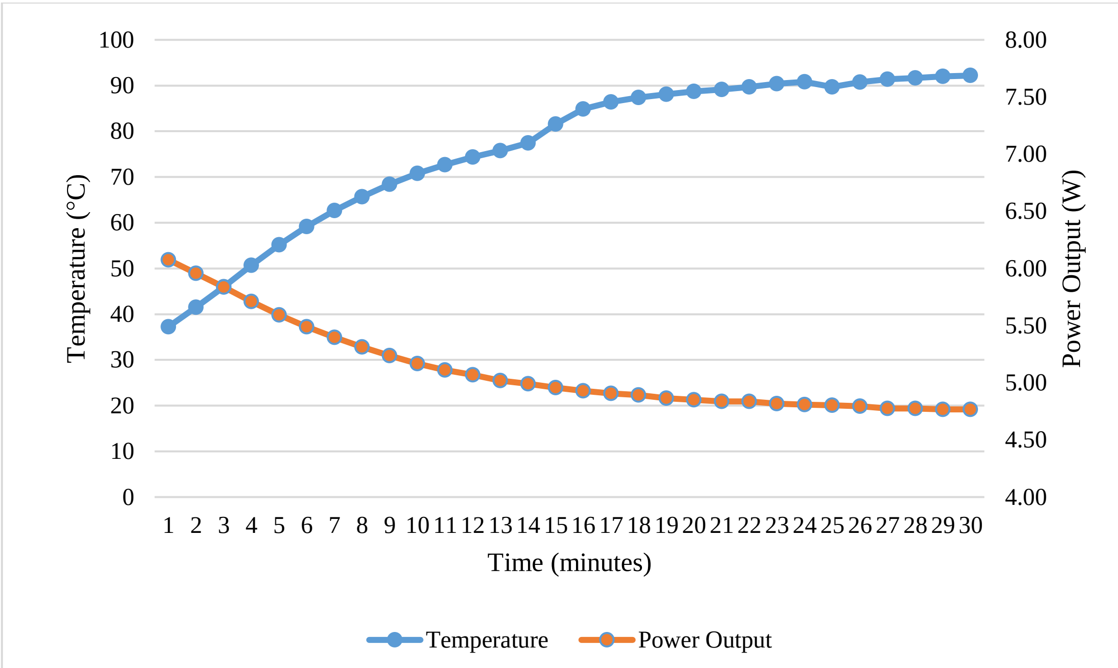

Figure 4. The correlation between temperature and output power on solar panels when the spray timing delay is 30 minutes.

In **Figure 4**, it can be seen that there is a decrease in the output power from 6.08 W, down slowly until it reaches 4,77 W for 30 min, followed by an increase in the temperature of the solar panel, which was initially 37.26^{0}C until it reached a temperature of 92.18^{0}C, and the output power of the solar panel is inversely proportional to its temperature; if the temperature of the solar panel continues to increase, a value will be obtained that will decrease the output power of the solar panel and vice versa(Zaini et al., 2015). The sensitivity of the semiconductor material in solar panels to changes in temperature is the cause of the increase in temperature in solar panels, resulting in a decrease in the rate of electron transfer.

3.1 Effect of Delay Timing Spray on Increasing and Decreasing Solar Panel Temperature

The study was conducted over a period of 60 min. In Figure 5, at a spray delay time of 30 min, the highest temperature was achieved with a value of 92,66^{0}C and the lowest temperature during cooling was 47,43^{0}C. At a spray delay time of 20 min, the highest temperature was achieved with a value of 88,87˚C and the lowest temperature was 42,91^{0}C, while at a spray delay time of 10 min, the highest temperature was achieved with a value of 76,28^{0}C and the lowest temperature during the cooling process was 39,43^{0}C.

The cooling frequency influenced the differences in each test. The more often cooling is carried out, the lower the temperature of the solar panel. In addition, the spray timing delay also influences it. The longer the delay, the higher is the temperature. With a spray delay time of 10 min, the highest temperature reached was 76,28⁰C, and the lowest temperature during the cooling process was 39,43⁰C.

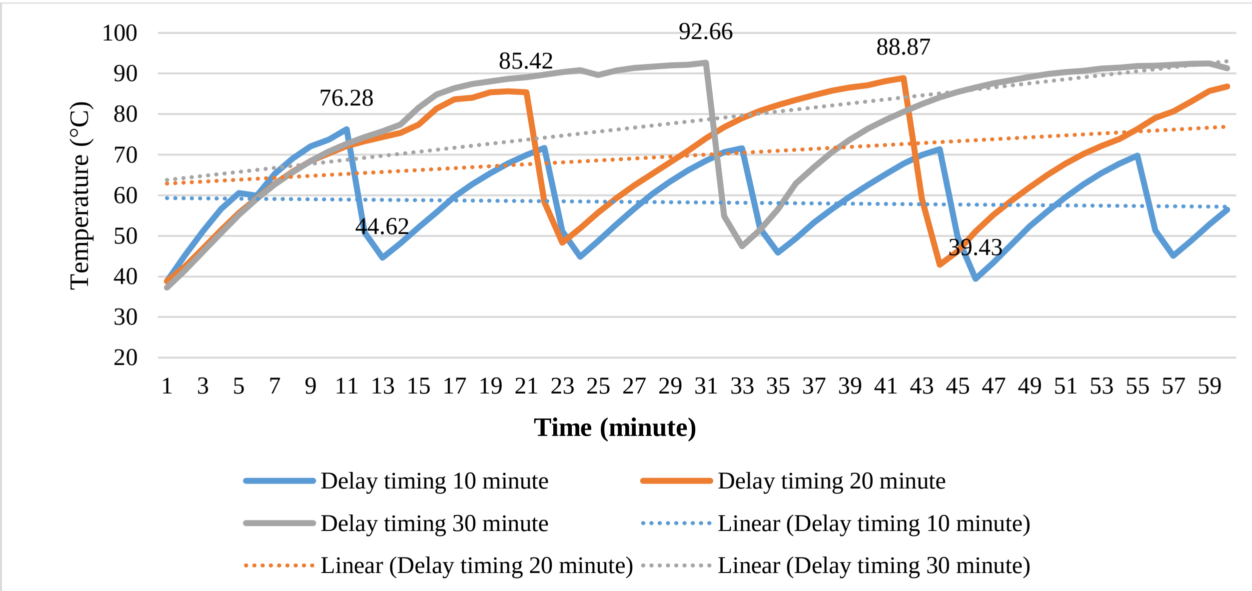

Figure 5. The correlation between temperature increase and decrease when the spray timing delay is 10, 20, and 30 minutes.

3.2 Effect of Delay Timing Spray on the Increase and Decrease in Top Surface Temperature of Solar Panels

Figure 6 shows that, at a delay time of 30 min, the highest temperature was achieved with a value of 97.37⁰C, and the lowest temperature during cooling was 50.8⁰C. At a spray delay time of 20 min, the highest temperature was achieved with a value of 93.25⁰C, and the lowest temperature was 45.22⁰C, At a spray delay time of 10 min, the highest temperature was achieved with a value of 78.25⁰C, and the lowest temperature during the cooling process was 40.85⁰C. The highest cooling occurred when the spray timing delay was 10 min, the highest temperature reached 78.25⁰C, and the lowest temperature when cooling occurred was 40.85⁰C.

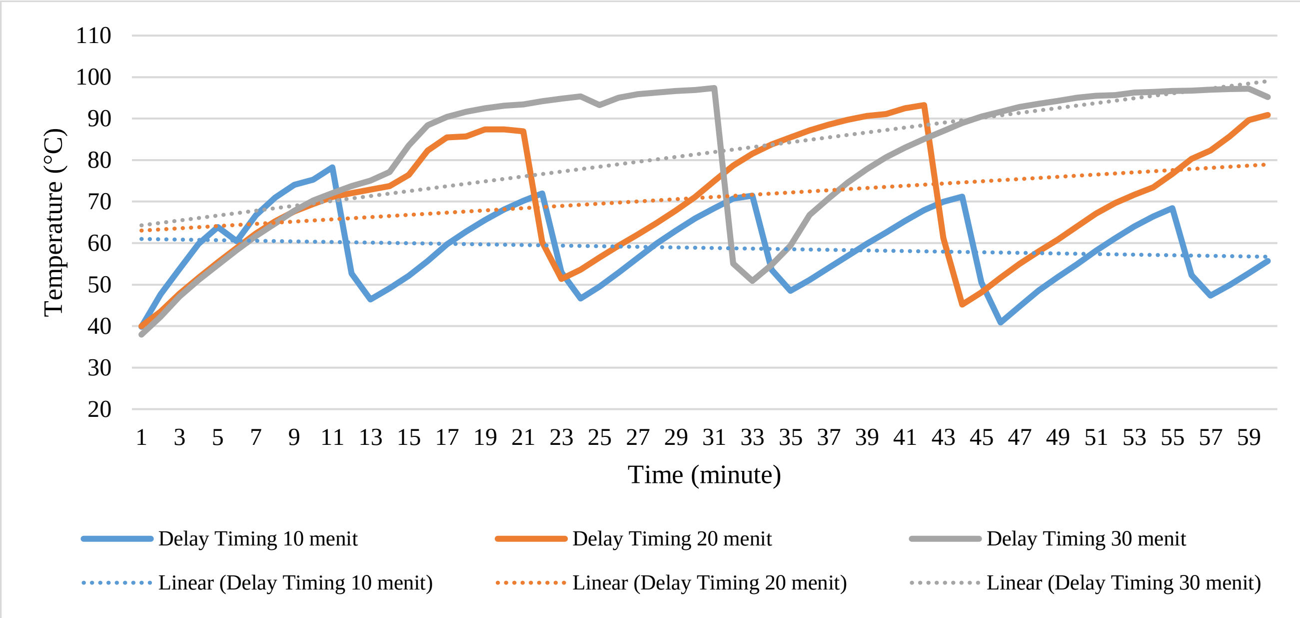

Figure 6. The correlation between the increase and decrease in upper surface temperature when the spray timing delay is 10, 20, and 30 minutes.

3.3 Effect of Delay timing spray on the Increase and Decrease in Lower Surface Temperature of Solar Panels

Figure 7 shows that at a spray delay of 30 min, the highest temperature was achieved with a value of 85,60⁰C, and the lowest temperature during cooling was 42,28⁰C. At a spray delay time of 20 min, the highest temperature was achieved with a value of 82,60⁰C and the lowest temperature amounted to 39,45⁰C, while at a spray delay time of 10 min, the highest temperature was achieved with a value of 73,63⁰C and the lowest temperature during the cooling process was 37,30⁰C. The best cooling was obtained when the delay was 10 min, with the highest temperature achieved at 73,63⁰C and the lowest when the cooling occurred at 37,30⁰C. At a delay time of 10 min, in a straight line, the panel experienced only a small increase in temperature compared with the initial temperature before cooling.

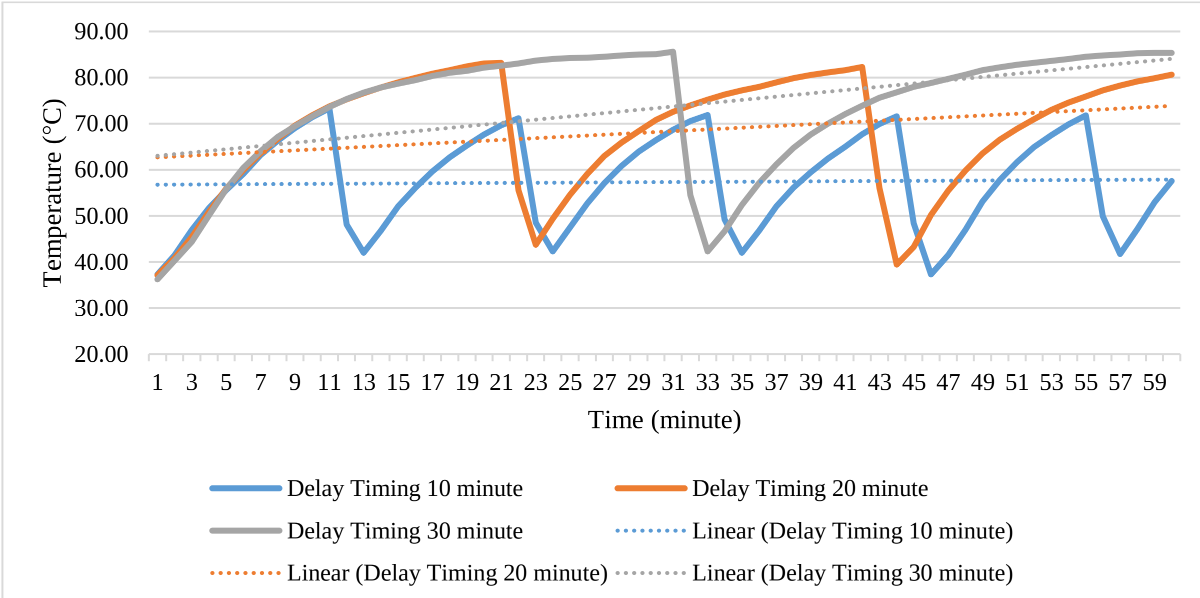

Figure 7. The correlation between the increase and decrease in bottom surface temperature when the spray timing delay is 10 minutes, 20 minutes, and 30 minutes.

Figure 8 shows that during the delayed spray timing, the top surface of the panel experienced a higher temperature increase than the bottom surface of the panel. The factor that influences this phenomenon is that the solar simulator is exposed to direct sunlight on the top surface of the panel. In contrast, the bottom surface is not exposed to direct sunlight.

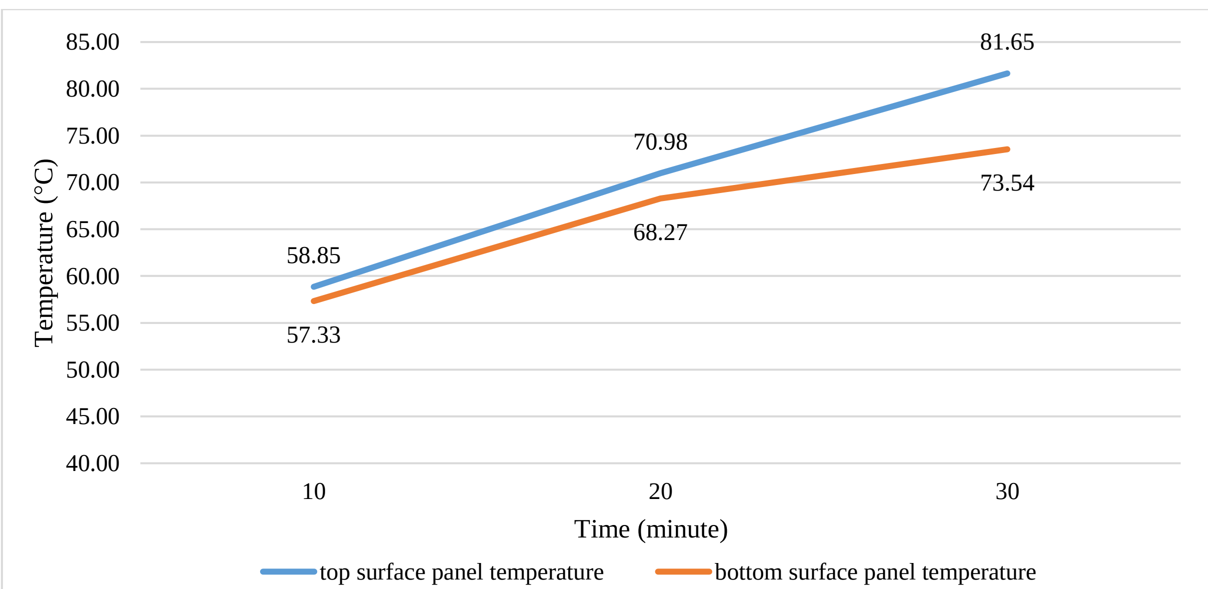

Figure 8. Comparison of the temperature of the top and bottom surfaces of the panel when the spray timing delay was 10, 20, and 30 minutes.

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3.4 Effect of spray timing delay on average temperature of solar panels for 1 hour

Figure 9 shows that the lowest average temperature occurred when the spray timing delay was 10 min (58,95^{0}C), while the highest average temperature was obtained when the spray timing delay was 30 min (78,63^{0}C).

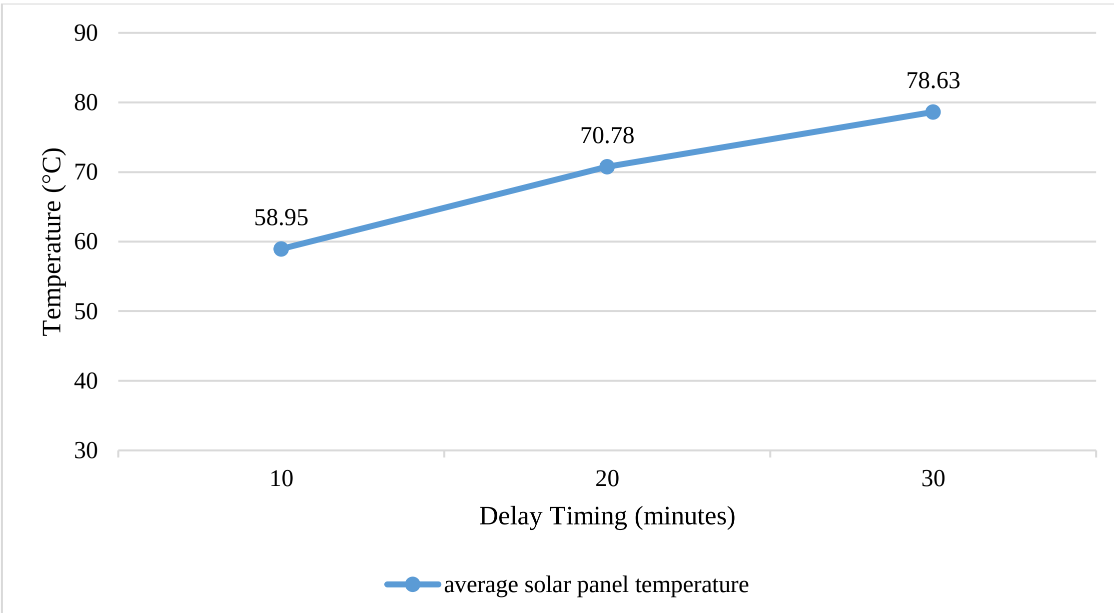

Figure 9. The correlation between the average temperature of solar panels and the delay timing spray.

The delay timing also influenced this difference. Spray: When the delay timing of the spray is long, the cooling frequency of the solar panel is also small, causing temperature on the panel. Solar energy increases; conversely, if the spray delay timing is faster, the cooling frequency of the solar panel will increase, thus lowering the temperature.

From Table 2, it can be seen that the lowest average temperature occurred when the spray timing delay was 10 min. It is 52,98^{0}C. In comparison, the highest average temperature was obtained when the spray timing delay was 30 min, 81,65^{0}C, and the delay timing is 20 min (70,98^{0}C).

Table 2. Comparison of delayed timing spray with average temperature on top solar panel surface.

Delay timing spray **(minute)**	**Average solar panel temperature (^{0}C)**
10	58,85
20	70,98
30	81,65

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3.5 Wasted Thermal Energy

According to Almanda and Piliang (2019), a water-coolant cooling system is more efficient than mineral water and seawater, with efficiency ratios of 15,41%, 14,45%, and 13,50%, respectively. Based on Equation (3), the total heat energy released in 1 h was obtained (see Table 3).

Table 3. The total heat energy released for an hour.

No	Delay Timing Spray 10 (minutes)		Delay Timing Spray 20 (minutes)		Delay Timing Spray 30 (minutes)	
	Energy (Watt)	Energy (J)	Energy (Watt)	Energy (J)	Energy (Watt)	Energy (J)
1	1,66	99,62	2,61	156,55	3,95	237,19
2	2,61	156,55	3,51	210,31		
3	2,19	131,25				
4	2,27	135,99				
5	2,24	134,41				
Total	10,96	657,81	6,11	366,86	3,95	237,19

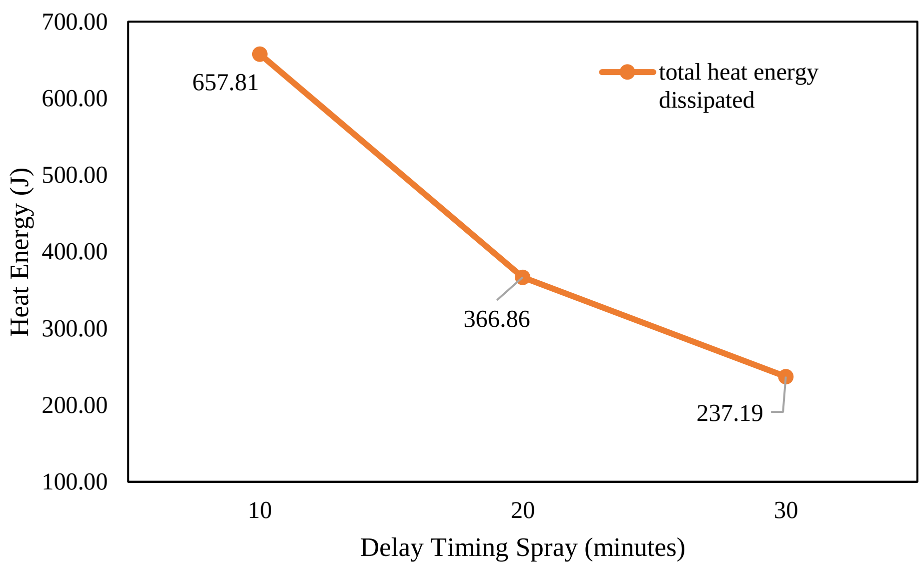

Figure 10. Comparison of delay timing spray with the total heat energy dissipated by the solar panel.

In Figure 10**,** the highest total heat energy dissipated occurred when the spray timing delay was 10 min, namely 657,81 J, and the lowest occurred when the spray timing delay was 30 min, 237,19 J. This difference was influenced by the spray frequency used in each test. Thus, the more spray there is, the more heat energy dissipated on the solar panels (Armendáriz-Ontiveros et al., 2022).

Based on Equation (4), the coolant delay timing spray was obtained for 10, 20, and 30 min and the average temperature of the solar panels (see Table 4).

Table 2. ΔTLM on delay timings spray of 10 minutes, 20 minutes, and 30 minutes.

Delay Timing Spray **(minute)**	**Number of sprays**	**ΔT_{LM} (K)**
10	1	23,03
	2	22,43
	3	17,52
	4	10,94
	5	16,65
20	1	19,55
	2	13,10
30	1	17,21

Based on Equation (5), the heat transfer coefficient was obtained using cooling data recorded every minute for (1 hour) (see Figure 11).

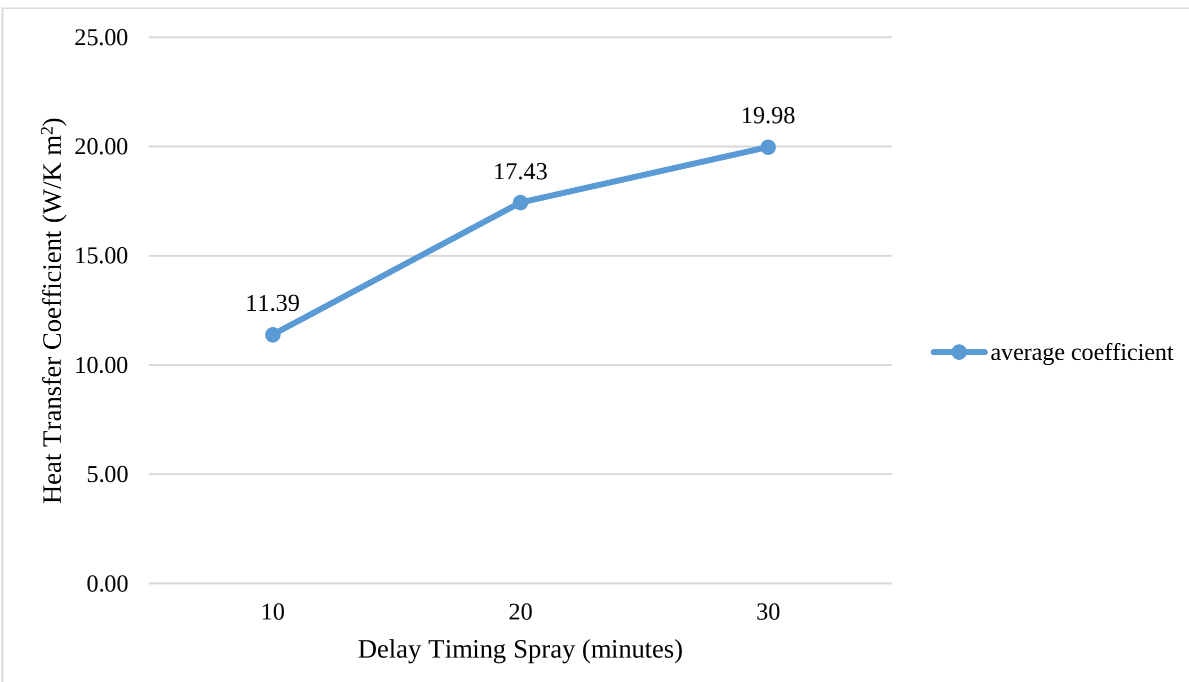

Figure 11. The correlation between delay timing spray and average heat transfer coefficient.

Figure 11 shows that the heat-transfer coefficient increased as the spray delay time increased. At a 10-minute delay, the coefficient is 11.39 W/K·m^2, rising to 17.43 W/K·m^2 at 20 minutes, and reaching 19.98 W/K·m^2 at 30 minutes. This trend could be attributed to several factors. First, with longer spray

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intervals such as 30 min, the panel reached higher temperatures before each spray. This larger temperature difference between the panel and coolant increases the heat transfer coefficient because greater thermal gradients drive faster heat transfer. Additionally, the higher panel temperature at longer intervals allowed each spray to cool the surface more effectively, boosting the heat transfer rate during each spray cycle. Shorter intervals (e.g., 10 min) maintain a more consistent lower panel temperature, but a smaller temperature gradient results in a lower overall heat transfer coefficient, even though the cooling frequency is higher. These observations suggest that while a 30-minute delay maximizes the heat transfer coefficient, it also allows the panel temperature to increase further, which could impact the overall panel performance. The temperature difference influences the difference in the average value of the heat transfer coefficient: the higher the temperature difference on the solar panel, the higher the heat transfer coefficient value (Armendáriz-Ontiveros et al., 2022).

3.6 Effect of Delay Timing Spray on Efficiency and Output Power Produced by Solar Panels

In calculating the efficiency and output power of the solar panels, the data were recorded every minute for (1 hour), so that later you will know the total output power was calculated based on equation (1) and the efficiency of each delay timing spray (see Table 5).

Table 3. Total energy produced by solar panels.

Delay timing spray (minute)	Total energy produced in 1 hour (J)	Total energy produced in 1 hour (kWh)
10	20150,78	$5{,}60 \times 10^{-3}$
20	18976,11	$5{,}27 \times 10^{-3}$
30	18383,68	$5{,}11 \times 10^{-3}$

The radiation intensity of the halogen-type spotlight (E) with a power of 1000 W was calculated using Equation (7). Based on the luminous intensity value of 13051,35 lm/m^2 and luminous efficacy of 18 lm/W, the radiation intensity was 725,08 W/m^2. The total electrical efficiency obtained by the solar panel was then calculated when the spray timing delays were 10, 20, and 30 min (see Table 6).

Table 6. Electrical efficiency of solar panels.

Delay timing spray (minute)	Total power (J)	Total power (kWh)	Electrical Efficiency of solar panels (%)
10	20150,78	$5{,}60 \times 10^{-3}$	1,12%
20	18976,11	$5{,}27 \times 10^{-3}$	1,05%
30	18383,68	$5{,}11 \times 10^{-3}$	1,02%

The results in Table 5 indicate that the maximum total power output and solar panel efficiency during one hour were achieved with a spray timing delay of 10 min. The corresponding total output power and efficiency values were 5.60×10^{-3} kWh and 1.12%, respectively. Conversely, the lowest

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performance was observed with a 30-minute spray timing delay, yielding a total output power of 5.11 × 10^{-3} kWh and an efficiency of 1.02%. The efficiency values were calculated using Equation (1), which incorporates the fill factor (FF) as an estimated parameter to account for the relationship between electrical output and solar energy input. This method provides an approximate efficiency based on the available data. This discrepancy highlights the impact of the spray timing on the solar panel performance. A longer delay increases the panel temperature, which subsequently slows down the heat transfer and reduces the electrical power output. Because power output and efficiency are directly proportional, a decrease in one result in a decline in the other.

3.7 Multivariate Analysis of Variance Test (MANOVA)

The step to determine this effect was to carry out a MANOVA test, along with the variables and the results of the MANOVA test, which was carried out using the SPSS software (see Tables 7–9).

Table 7. Variable independent and dependent.

Variabel *Independent*	**Variabel *Dependent***
method *Delay timing spray* (10, 20, 30) minute	(Temperature, Open Circuit Voltage (Vp), Short Circuit Current (Ip))

Table 8. Multivariate Test.

Multivariate Tests[a]								
Effect		**Value**	**F**	**Hypothesis df**	**Error df**	**Sig.**	**Noncent. Parameter**	**Observed Power[d]**
Delay timing	Pillai's Trace	.380	13.747	6.000	352.000	<,001	82.483	1.000
	Wilks' Lambda	.643	14.427[b]	6.000	350.000	<,001	86.561	1.000
	Hotelling's Trace	.521	15.106	6.000	348.000	<,001	90.634	1.000
	Roy's Largest Root	.442	25.924[c]	3.000	176.000	<,001	77.771	1.000

The MANOVA test with Wilks' lambda was used to determine the average difference between the independent and dependent variables when the assumptions of normality and homogeneity were met (Walpole et al., 2011).

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Hypothesis:

H_0: There is no significant difference simultaneously caused by the Independent Variable (Delay Spray Time) and the Dependent variable (Temperature, Open Circuit Voltage, and Short Circuit Current Strength)

H_1: There is a significant difference simultaneously caused by the Independent Variable (Delay Spray Time) and the Dependent variable (Temperature, Open Circuit Voltage, and Short Circuit Current Strength)

α: 5% or 0.05

Decision: Based on the multivariate test results, the Wilk's lambda value was 0,643 with a significance value of 0,001 < 0,05 (α). So, it is necessary to reject H_0 and accept H_1

Interpretation: With an α of 5% or a confidence level of 95%, it can be concluded that there is a significant difference simultaneously caused by the Independent Variable (delayed spray time) and the dependent variable (Temperature, Open Circuit Voltage, and Short Circuit Current Strength). With α 5% or a confidence level of 95%, it can be concluded that a significant difference is simultaneously caused by the Independent Variable (Delay Spray Time) and the Dependent variable (Temperature, Open Circuit Voltage, and Short Circuit Current Strength).

Table 9. Tests of Between-Subjects Effects.

Tests of Between-Subjects Effects								
Source	***Dependent* Variable**	**Type III Sum of Squares**	**df**	**Mean Square**	**F**	**Sig.**	**Noncent Parameter**	**Observed Power[d]**
Delay Timing	Temperature	12298.958	2	6149.479	35.431	<,001	70.863	1.000
	Open Circuit Voltage	44.186	2	22.093	31.039	<,001	62.078	1.000
	Short Circuit Current	.005	2	.002	28.061	<,001	56.122	1.000

a) Delay Spray Time Hypothesis with Temperature

H_0: There is no significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Temperature)

H_1: There is a significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Temperature)

α: 5% or 0.05

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Decision: Based on the results of the Tests of Between-Subjects delayedtsprayetimealue was 3 dependent th a signiftemperaturee voltage,1 < 0electric currentrstrengthuse H_0 and accept H_1

Interpretation: With α 5% or a confidence level of 95%, it can be concluded that there is a significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Temperature)

b) Delay Spray Time Hypothesis With Voltage

H_0: There is no significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Voltage)

H_1: There is a significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Voltage)

α: 5% or 0.05

Decision: Based on the tests of between-subject effects, the F value was 31.039, with a significance value of 0.001 < 0.05 (α). Decision: Based on the Tests of Between-Subjects Effects results, the F value was 31.039, with a significance value of 0.001 < 0.05 (α). So, it is necessary to refuse H_0 and accept H_1

Interpretation: With an α of 5% or a confidence level of 95%, it can be concluded that there is a significant difference between the Independent Variable (delayed spray time) and dependent variable (voltage).Interpretation: With an α of 5% or a confidence level of 95%, it can be concluded that a significant difference is caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Voltage).

c) Delay Spray Time Hypothesis with Electric Current

H_0: There is no significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Electric Current)

H_1: There is a significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Electric Current)

α: 5% or 0.05

Decision: Based on the results of the tests of between-subject effects, the F value was 28.061, with a significance value of 0.001 < 0.05 (α). Decision: Based on the results of the Tests of Between-Subjects Effects, the F value was 28.061, with a significance value of 0.001 < 0.05 (α). So, it is necessary to refuse H_0 and accept H_1

Interpretation: With α 5% or a confidence level of 95%, it can be concluded that there is a significant difference caused by the Independent Variable (Delay Spray Time) to the Dependent variable (Electric Current)

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4. Conclusion

Based on the results of the experimental studies on PV, the following conclusions can be drawn: Based on the results of experimental studies on PV, it can be concluded as follows: The solar panel temperature dropped the most with a 10-minute spray delay, reaching 58.95⁰C. For 20 and 30-minute delays, the temperatures were higher at 70.78⁰C and 78.63⁰C, respectively. This shows that shorter spray delays are more effective in reducing panel temperatures.

Reducing the panel temperature increased the output power. The highest output power and efficiency (5.60×10^{-3} kWh and 1.12%, respectively) occurred with a 10-minute spray delay. At 20 minutes, values dropped to 5.27×10^{-3} kWh and 1.05%, while the lowest, 5.11×10^{-3} kWh and 1.02%, was recorded at 30 minutes. These results demonstrate the critical impact of the spray timing on the solar panel performance.

The cooling method with spray delays of 10, 20, and 30 minutes resulted in power outputs of 20150.78 J, 18976.11 J, and 18383.68 J, respectively. The highest output was achieved with a 10-minute delay, indicating that shorter spray delays enhance the cooling efficiency and power performance.

Statistically, the MANOVA test was used to determine the effect of the Independent Variable (Pulsed-Spray Time) on the dependent variables (Temperature, Open Circuit Voltage and Short Circuit Current). Statistically, the MANOVA test determines the effect of the Independent Variable (Pulsed-Spray Time) on the Dependent Variable (Temperature, Open Circuit Voltage and Short Circuit Current). With α 5% or a confidence level of 95%, it can be concluded that a significant difference is simultaneously caused by the Independent Variable (Delay Spray Time) and the Dependent variable (Temperature, Open Circuit Voltage and Short Circuit Current Strenght).

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