# Water and Heat-sink Cooling System for Increasing the Solar Cell Performances

S. Suherman<sup>1,\*</sup>, A.R. Sunarno<sup>1</sup>, S. Hasan<sup>1</sup>, R. Harahap<sup>1</sup>

<sup>1</sup>Universitas Sumatera Utara, Medan, Indonesia

# Abstract

Solar panel comprises some solar cells in series and parallel arrangements converting sunlight into electrical current in usable level. However, the cell arrangement causes large surface area exposed to sunlight that tends to be heat absorbent. Existing study shows that the efficiency of solar cell decreases about 0.5% for each 1°C-surface temperature increment. Various cooling systems for solar cells have been offered by many researchers. This paper proposes a passive cooling system that combines water-filled aluminium blocks and heat-sinks. The water-filled aluminium blocks absorb heat from the back of solar cells and the heat-sinks release this heat to the air. The experimental assessment showed that the proposed method is able to reduce surface temperatures about 11.91% lower than the non-cooled solar panel. Compared to the existing methods, the proposed coolant achieved 5.08% and 7.37% lower surface temperatures than water and heat-sink coolant subsequently. The proposed cooling system also exerted at least 6.28% higher power than the other methods.

Keywords: Solar cell, surface temperature, passive cooling system, water and heat-sink cooling system.

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# 1. Introduction

Solar energy is the easiest energy source to harvest as sunlight is freely available during daylight. In some areas such as in tropical countries, sunlight is available whole days in a year. As one of the alternative sources, solar energy is the most potential source to reduce fossil energy dependency. Solar energy travels from the sun to the earth surface in two forms: light and heat [1]. Both forms are convertible energy sources. The first form is converted to electrical energy by using photon sensitive material, which is referred to as solar cell. The second form, heat, is converted to usable energy by using mechanical process.

Light conversion into electrical energy is achieved by using doped silicon materials that produce electron excitations when exposed to photon [2]. In its conversion process, electron movement decreases in presence of heat that comes along with sunlight. Heat causes silicon material performance rapidly decreases. The number of electron excitations is reduced by the surface temperature increment.

An existing study concluded that solar cell efficiency decreases about 0.5% for every 1°C-surface temperature increment as depicted in Figure 1 [3]. Output power is smaller when surface temperature risen. Solar cell optimally converts sunlight only when it is exposed directly to the sun. However, continuous exposal causes surface temperatures increase rapidly. This increment reduces excitations and apparently decreases the performance. This reduction is unwanted as existing conversion efficiency is still less than 20% [4].

Efficiency increment on solar cell materials are not easily achieved, but the efforts on solar cell material researches are easily aggravated by the surface temperature. Therefore, sunlight exposal impact should be minimized as low as possible. Solar cell is not designed to deal with temperature increment. The marketed solar panel is also not equipped by cooling system. This gap produces additional efforts by researchers to resolve the surface temperature problems.



<sup>\*</sup>Corresponding author. suherman@usu.ac.id

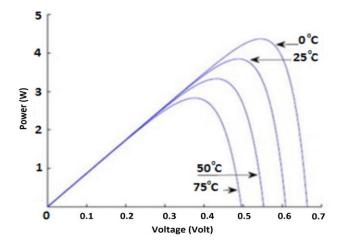


Figure 1. Surface temperature increment [3]

The cooling systems become an interesting research area to minimize surface temperature effect. There are two types of solar panel cooling systems: active and passive cooling systems [5]. Active cooling system can be applied in front and/or at the back of the solar cells by flowing a small amount of air or sprinkling water on the solar panel surface or at the back to compensate the heat. Active cooling system requires electrical energy to activate electrical fans or pumps to enable air or water flows. It uses energy produced by solar cells. In turn, even surface temperature successfully decreases, the overall efficiency may not increase significantly.

Figure 2 shows the water-cooling system that is driven by electrical energy proposed by some researchers mentioned by Siecker et al [6]. Water in a tank is pumped and filtered before sprinkled over the solar cell surface. The drain pipe is connected to a tank to safely reuse water.

Other researchers used electric fan to flow air through the solar cell surface. Even dough both DC water pump or DC brushless fan were claimed to be able increasing the solar panelefficiency [7], intensive analysis performed by Nizetic et al proofs that active cooling system is not economically viable [8].

On the other hand, passive cooling system does not consume electrical energy generated by solar cells. Passive cooling system decreased surface temperature by applying heat-sink or fixed water-cooling system to absorb the heat. Passive cooling systems have also been proposed by some researchers. For instance, Pradhan et al [9] decreased surface temperature of two solar modules of 20 watts 12 volts by using passive water-based cooling system which resulted 2% efficiency increment. Meanwhile, natural air ventilation and heat-sink combination proposed by Chen et al [10] successfully increased the efficiency of 100 WP solar panel from 12.9% to about 13.2% for U-shape heatsink and 14.7% for L-shape heat-sink. Increasing flowing air improved efficiency further up to 24.7%.

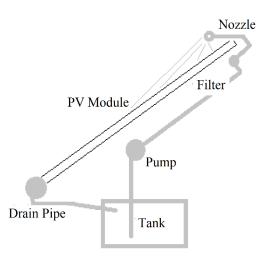


Figure 2. Active water-cooling system

In small size applications, the aluminum round pins heatsink (RPHS) and the aluminum straight fins heat-sink (SFHS) have been explored [11]. The SFHS type heat-sink performs better than RPHS. However, heat-sink size is the matter.

# 2. Proposed system

This paper proposes a passive cooling system by combining water-filled aluminum blocks and U-shape heat-sink, installed at the back of solar cells to decrease surface temperature. The water-filled aluminum blocks are attached uniformly and directly at the back of solar cell to absorb the heat. This heat is then taken by the U-shape heatsink and released to the air.

Figure 3 shows the sketch of the proposed cooling system installation. The solar panel size is  $31 \text{ cm} \times 126 \text{ cm}$ . I order to cover all the back-surface area, the solar panel requires about 9 aluminum blocks of 4.4 cm x 2.2 cm x 1 m that can be filled by 7.2-liter water. The installed U-shape heatsink has 12 fins with size of 12 cm x 3.5 cm x 40 cm. The total number of heatsink per solar panel is 4 modules. The designed system is compared to the basic solar panel, solar panel with water cooling system and heat-sink attached solar panel.

### 3. Research method

In order to evaluate the proposed cooling system performances, an experimental tool was set up, sensor circuits controlled by the Atmega328 microcontroller were assembled and several full days measurements were performed. The system was compared to existing water and heat-sink based passive cooling systems. Voltage, current, power and surface temperature characteristics were explored and analyzed.



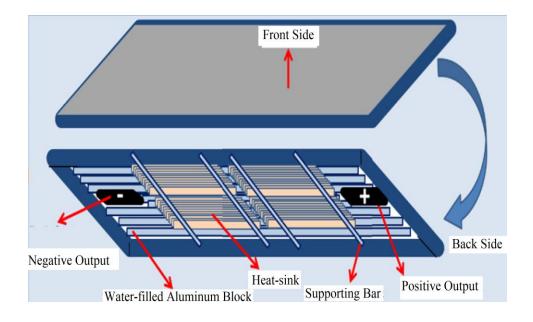


Figure 3. The proposed passive cooling system

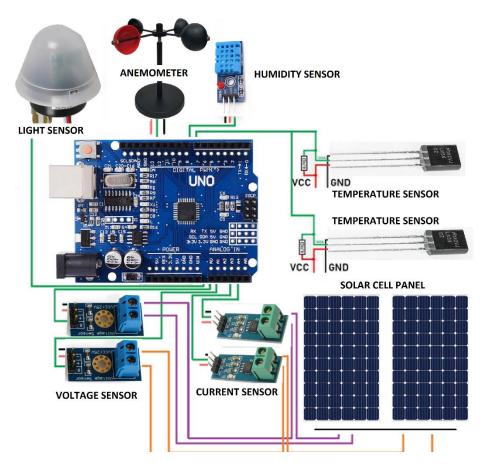


Figure 4. The measurement circuits

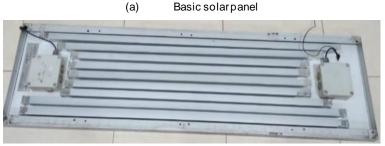


A circuit with some sensors controlled by an Atmega328 microcontroller [12] was designed to measure the aforementioned performances as depicted in Figure 4. The employed sensors are to measure surface temperature, room temperature, humidity, flowing current to dummy load, open circuit voltage, generated power, wind speed and solar radiation. Measurements were performed in Siguragura, Sumatera Utara, Indonesia, located in coordinate of  $2.523598^{\circ}$  and  $99.268270^{\circ}$ .

Figure 5 shows the construction of the observed solar panel. The objects of the experiment were 12 Volt solar panels of 50 WP. Four panels were employed for different cooling systems. Figure 5a is the basic solar panel, followed by water cooled and heat-sink cooled panels. The proposed system is depicted in Figure 5d where the water-filled aluminum blocks and heat-sink were arranged at the back solar panel. Measurement was performed simultaneously for four observed panels.



Basic solar panel



(b) Water cooled solar panel

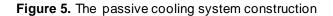


Heat-sink cooled solar panel

(c)



(d) The proposed water-heat-sink cooling system





Solar panels were assessed before cooling systems installed to make sure that fair comparison was performed. Adjustment was performed when needed.

In order to observed the performances, the four panels were evaluated in an open area at once so that these panels experience the same temperatures, radiations, humidity and wind speeds. Voltage, current and temperatures sensors were attached to each panel. Measurement data were stored in a computer. Measurements were performed for 7 days, repeated from 07.13 am. to 18.15 pm. The measurement set up is shown in Figure 6.



Figure 6. The evaluation set up

# 4. Measurement results

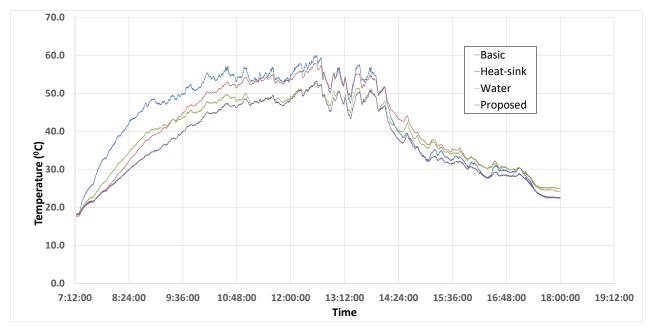
Figure 7 shows the measurement results. The obtained voltage, current and power were plotted according to the variations of surface temperature. From those images in Figure 7, temperature moves almost linearly from 07.13 am to 12.00, and decreases slowly in the afternoon. Rough variations may be caused by clouds during measurements.

Surface temperature, voltage, current, and power plots of the four panels are clearly separated from each other. The effect of cooling system is distinguishable. Generally, solar cell with the proposed cooling system consistently generated lowest surface temperature and highest plots for voltage, current and power.

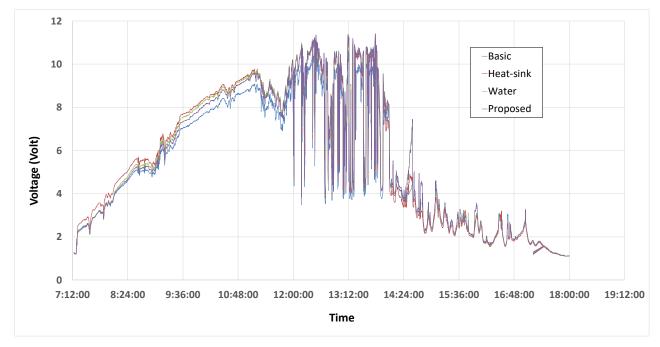
In term of surface temperature, the proposed cooling system made the surface temperature increases rather slowly in the morning and much slower in the afternoon. The maximum surface temperature achieves  $42.9^{\circ}$ C when panel is not cooled. The proposed method suppressed the average surface temperature down to  $33.39^{\circ}$ C, followed by the water coolant  $35.17^{\circ}$ C, heat-sink  $36.04^{\circ}$ C and basic solar panel of  $37.90^{\circ}$ C. This fact shows that the proposed cooling system is able to decrease surface temperature about 5.08% lower than water coolant, 7.37% lower than heat-sink and achieve 11.91% lower temperature than basic uncooled solar panel.

In term of the generated voltages, Figure 7b shows that the values are quite competing. The solar panel equipped by the proposed cooling system generated 4.1 volt in average. This value is similar to the generated voltage by solar panel with water coolant. Solar panel with heat-sink produced 4.03 volt and the basic panel exerted 3.87 volt in average. This also shows that the proposed system is not worse than the existing ones.



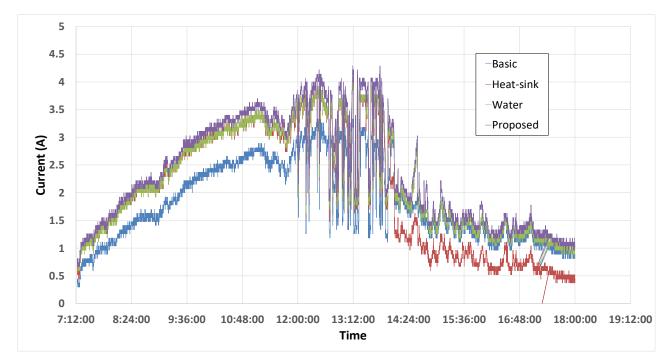


a. Surface Temperature Variation

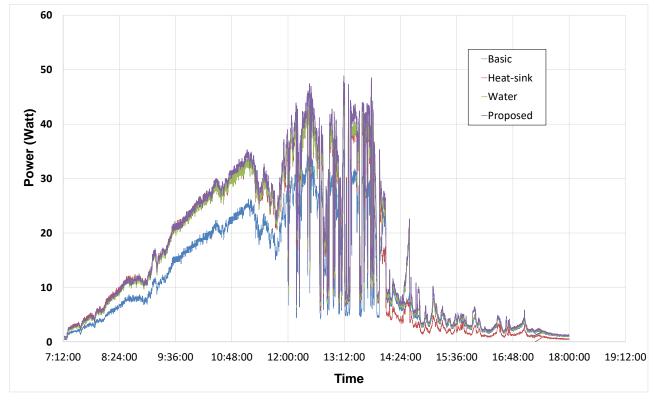


b. Measured Voltage





c. Measured Current



d. Measured Power

Figure 7. The measurement results



Meanwhile, the generated current performances as plotted in Figure 7c are very distinguishable. The charts are separated from one another as current flows at the same direction. The proposed method causes solar panel exerted current of 2.19 A, followed by water coolant 2.06 A, heatsink 1.96 A and basic uncooled panel 1.81 A.

Finally, the power produced by the solar panel equipped by the proposed method achieved 28.23% higher than basic uncooled solar panel. It is higher about 6.28% and 12.13% compared to water cooled solar panel and heat-sink cooled solar panel. The maximum power produced by the proposed cooled solar panel was 48.8 W.

All these explanations were based on data taken in the first day. The average power for 7-day measurements are shown in Table 1. The maximum throughput was obtained in day 3, producing 17.9W in average. This maximum output was achieved during the third day at about 13.00 pm. This maximum power occurred when the irradiance level achieved about 913.9 W/m<sup>2</sup>. These values were redrawn in Figure 8.

Table 1. Average output power

Day –	Average Power (Watt)			
	Basic	Heat-sink	Water	Proposed
1	11.3	14.3	14.9	15.7
2	4.8	5.2	5.8	6.3
3	6.0	6.9	7.4	8.0
4	14.5	15.1	16.3	17.9
5	10.3	12.0	12.4	13.2
6	5.3	6.3	6.4	6.5
7	9.8	11.1	11.6	11.9
Average	8.9	10.1	10.7	11.3

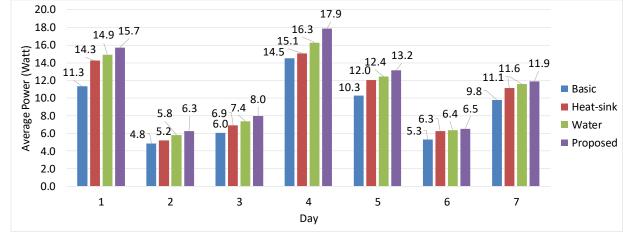


Figure 8. Daily power measurements

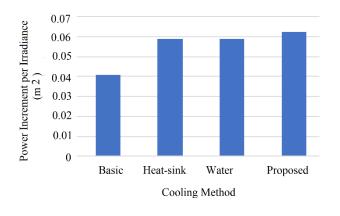


Figure 9. Power increment for irradiance increment

In addition to surface temperature, voltage, current and power characteristics caused by the cooling system, impact of irradiance increment was also analyzed. The power increment as result of increasing irradiance level is plotted in Figure 9. This figure shows that the proposed cooling system is able to make solar panel works efficiently as for irradiance increment of 1W/m<sup>2</sup> successfully drives power increment of 0.0624 Watt. This is 6.04% higher than both water and heat-sink and 53% higher than the uncooled solar panel. Another interesting property is the relation between irradiance intensity to how many powers generated by the solar panel. Figure 10 shows relationship between the output power of solar panel and the solar intensity. This figure shows only the proposed coolant and the uncooled panels. The generated power increases exponentially to incoming irradiation.



By using simple trend statistics, the uncooled panel generated power following Equations 1.

$$y = 0.00002(x - 220)^{2.0319} \tag{1}$$

where x is irradiance in  $W/m^2$  and y is power in Watt. The proposed coolant made the solar panel generated power following Equation 2.

$$y = 0.0001(x - 220)^{1.8024} \tag{2}$$

By combining both equations and performing approximation, Equation 3 was obtained. The value of  $0.00002(x-220)^{20319}$  is the capability of the solar panel, while value 0.0106(x-220)-2.0054) is the impact of the cooling system.

$$y = 0.00002(x - 220)^{2.0819} + 0.0106(x - 220) - 2.0054$$
(3)

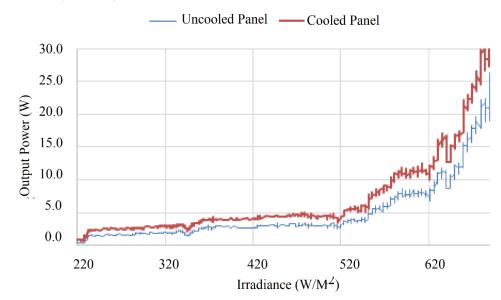


Figure 10. Power-irradiance relation

# 4. Conclusion

This paper has proposed a passive cooling system for solar panelusing a combination of water-filled aluminium blocks and U-shape heat-sink to reduce solar cell surface temperature. The assessment was performed experimentally. The proposed method was compared to existing water-cooling system and heat-sink cooling system as well as the basic uncooled solar cell. The surface temperature, voltage, current, and power characteristics were obtained as well as solar irradiation impact to power increment.

The experiment showed distinguishable characteristics for different cooling systems. The proposed method consistently reduced surface temperature and increased voltage, current and power the best among other evaluated passive cooling methods.

The proposed cooling system reduced surface temperature about 5.08% lower than water coolant, 7.37% lower than heat-sink coolant and 11.91% lower than basic uncooled solar cell. The experiments showed that the proposed method consistently reduces surface temperature during 12 hours 7 days measurements. The method decreases temperature about 5.08%, 7.37% and 11.91% lower than the compared panels. Its voltage performance was similar to water coolant, generated about 4.1 volt in average, but higher than heat-sink and basic solar cell. The proposed method exerted average current of 2.19 A, followed by water coolant 2.06 A, heat-sink 1.96 A and basic panel 1.81 A. The proposed method generated 28.23% power increment. Finally, the solar panel with the proposed cooling system is more efficient in responding irradiance increment compared to other cooling system.

#### Acknowledgements.

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