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Study on Thermoelectric Cooler Driven by Solar Energy in Medan City

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Abstract

The article aims to determine the performance of thermoelectric cooler driven by solar energy in Medan city. In a remote area where electricity is still not available can use this cooler box to store beverage such as drink cup so can maintain the freshness. The solar thermoelectric cooling system is based on the Peltier effect to create hot and cold side conditions. The cold side is used for cooling purposes to the cooling room. Heat from the heat side of the module is discharged into the surrounding environment using a heat sink and fan. Experimental results show that the solar thermoelectric cooler can reduce the drink cup temperature from 26^{o}C to 15^{o}C in about 40 minutes. The maximum COP of the cooling system during the experiment was calculated and found to be about 0.356. The effect of weather conditions on the COP value was about 85.90%.

Keywords: thermoelectric, drink cup, performance, solar energy

1. INTRODUCTION

The cooling system is an essential process for controlling the temperature of the product in industrial fields [1]. The conventional domestic refrigerators use the vapor compression cycle this time. The coefficient of performance (COP) of the refrigerators based on a vapor compression system is good enough, but the refrigerants used in such systems have problems in the global environment. Other cooling systems such as thermoelectric cooling based on the Peltier effect have essential advantages compared to conventional steam cycles even though the COP value is not as significant as the vapor compression systems [2]. Compared to vapor compression systems, thermoelectric cooling systems have the benefit of being free of refrigerants, shorter system, lower noise and vibration, good temperature control, and fewer maintenance requirements. [3]. Besides, they possess advantageous it can be powered by solar energy through photovoltaic cells [4,5]. The solar thermoelectric cooling is a particular cooler that uses solar energy as a substitute for conventional energy to drive thermoelectric equipment to be used to cool a room or object. In general, the components of a solar cooler system include thermoelectric modules, photovoltaic cells, cooling box, insulators, heat sinks, and cooling fans. The photovoltaic cells generate electrical energy to thermoelectric refrigeration. The research purpose to determine the performance of the thermoelectric cooling driven by solar energy.

2. RELATED WORKS

The thermoelectric cooling system is an electrical solid state refrigerant component that can serve as a heat pump for cooling. The principle is by using thermoelectric effect where the cold side is used for cooling purposes, and the hot side is used to release heat from the cold side to the environment by utilizing heat sink and fan [6]. On the side of the thermoelectric cooling system that absorbs heat, there is a cooling effect, and this is used for various cooling processes. Another term for thermoelectric cooling systems is Peltier cooling. The thermoelectric cooling system utilizes the Peltier effect that first discovered by Jean Charles Athanase Peltier in 1834. Briefly, it can be said that the Peltier effect is an effect of heat on one side and cooling effect on the other side when the direct current passed in a circuit of two different types of materials connected [7,8]. The material is a thermoelectric elemental material made from semiconductor material. In general, the advantages of a thermoelectric cooling system are practical because of their small shape, easy installation and does not involve complicated mechanical supports. This system can be applied to portable cooling devices, not easily damaged, during voltage, current and heat treatment accordingly with its provisions as well as predicted to be able to use thereabouts 100,000 hours. The drawback is the limited ability of cooling and low efficiency. Note that thermoelectric cooling system efficiency ranges from 10-15% [9,10]. Applications which often use the thermoelectric cooling system are a cooling processor, air conditioning, refrigerator on the dispenser, beverage cooler, and temperature aquarium control. The COP value of thermoelectric refrigeration is the ratio between the resulting heat of the thermoelectric and the energy supplied. The COP value of thermoelectric cooling system can be determined from equation [11, 12]:

$$COP = \frac{Q_{cooling}}{W_{in}} \quad (1)$$

Where the cooling capacity (W) is

$$Q_{cooling} = m.\, C_p.\, \Delta t \quad (W) \quad (2)$$

and W_{in} is energy supplied through photovoltaic cells (W).

3. MATERIALS

This study uses the TEC1-12706 thermoelectric module. The cooler use two batteries to provide power to the Peltier components. To provide a power supply to battery from solar energy then used two modules of the solar panel. The solar charge controller (SCC) with 12 V and 10 A is used to adjust the current for charging from solar panels to batteries to avoid overcharging and monitor the battery temperatures. The cooling box system is connected to a data acquisition system, Cole Parmer 18200-40 via a thermocouple which is set on the component. The temperature was measured using a J type thermocouple with an accuracy of ±0.4%. The HOBO micro station data recording device is used to record weather conditions such as radiation intensity, air temperature, and relative humidity. The environmental temperature and relative humidity (RH) were measured using a HOBO sensor with an accuracy of ±0.2°C and ±2.5%, respectively. A pyranometer with an accuracy of ±5% is used to measure the intensity of solar radiation. As the local time, Medan city uses Western Indonesian Time or WIB (Waktu Indonesia Barat). The cooled objects used drink cups. The Peltier cooler box is isolated with 10 mm plywood on the outside, styrofoam with 40 mm in the middle and aluminum foil with 1 mm inside to minimize the influence of the air infiltration. The top cap is mounted bolts that can be opened-close to seal the cover of the cooling box further.

4. THE LAYOUT EXPERIMENTAL

The experimental process was done starting at 09.00 WIB with the power supply the battery begins to be activated and deactivated at 17.00 WIB. The battery is activated by connecting the cable from the SCC to the battery for eight hours so that the acquisition data can record the temperature changes that occur. The dimension of cooler box namely length 36 cm, wide 28 cm, and height 26 cm. The type of Peltier used is four pieces of TECl-12706. The Peltier components comprise four heatsink, four cold sinks, and four small fans. This experiment uses two pieces (@100 W) of the photovoltaic cells. The thermoelectric cooler is deactivated at 17.00 WIB and data of temperature changes have been obtained. The test on the next day again repeated with the same procedure starting at 09.00 WIB. The experiments were conducted for five consecutive days in February 2018 in Medan city. Figure 1 shows the outside and inside of the solar thermoelectric cooler tested. Figure 2 shows the experimental scheme of this research.

(a) (b)

Figure 1. (a) The outside of a cooler box (b) The inside of a cooler box

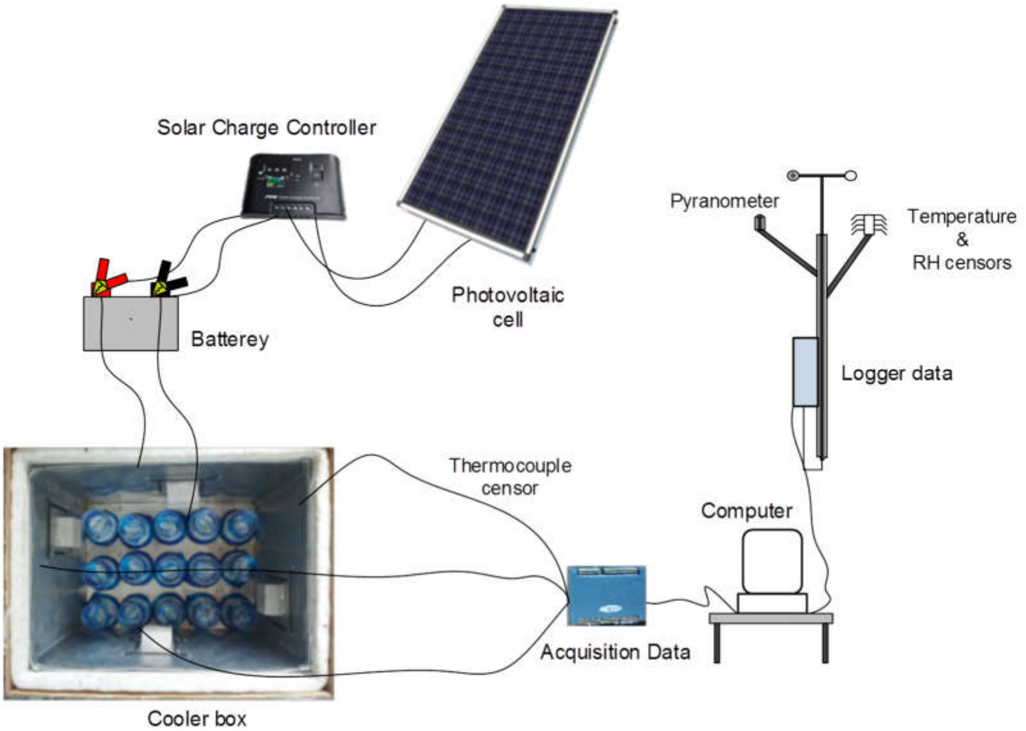

Figure 2. The layout experimental

5. EXPERIMENT AND ANALYSIS

5.1 Weather Condition

The tests are carried out in open locations that experience direct solar radiation. The weather conditions need to be known because relate to the performance of the photovoltaic cells used. The photovoltaic cells absorb the energy of solar radiation and stored into batteries. The battery power uses to drive the Peltier components in the cooling process. The process of measuring the weather conditions is carried out in five days. The measurement time range is done in one minute. Table 1 shows the weather conditions parameters during experiments.

Table 1. Weather conditions during experiments

Day	Average ambient temperature (°C)	Average relative humidity (%)	Average solar radiation (W/m²)
1	29.65	63.06	187.23
2	29.11	79.21	178.22
3	28.97	81.87	165.32
4	29.78	77.11	162.44
5	28.34	82.21	166.35

The measured weather parameters were temperature, humidity, and solar radiation intensity. The conditions of radiation measurements and solar radiation on theoretical calculations on the first day is shown in figure 3. There is a difference of results because in the calculation of solar radiation simulation results assumed that the condition of the sky is bright while on the measurement result is the actual condition of the sky can be sunny and cloudy. Based on the experimental data obtained from the measurement results that generally the solar radiation appear from 06.20-18.32 WIB for five days of experiments.

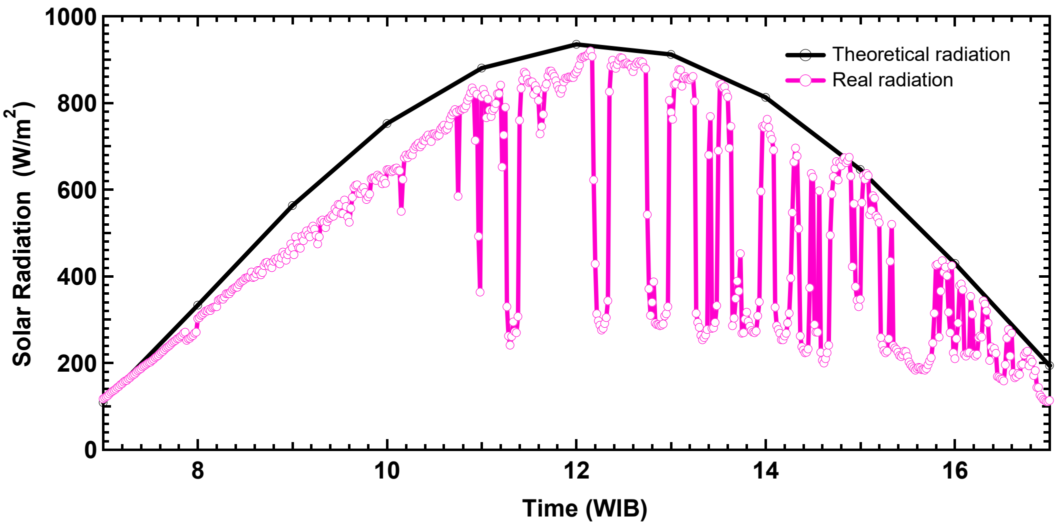

Figure 3. Typical of the intensity of solar radiation in the first day

5.2 Photovoltaic Performance

The Peltier refrigeration system uses solar cell panel components to absorb solar radiation to generate electrical energy. To calculate the estimated power of PV modules required it is necessary to know the average power needed by the cooling system every day. The electronic equipment used in the cooler is four small fans with a power of 1.8 watts each and four thermoelectric type TEC1-12706 with a power of each 72 watts. Average electricity usage for 8 hours for one day is 2361Wh. Since the electricity usage of PV is 100%, then the required PV output per day is 2361 Wh. As a note that for the calculation of power estimation power is then assumed the conditions of sunny weather with the intensity of solar radiation an average of 8 hours per day. In this study, also used batteries that serve to store electrical energy that has been generated by PV modules and used as an energy source to drive the fan and Peltier components. The battery used has a specification of 12V, 70Ah. The value of voltage and current coming out of solar panels ranges from 18.9 V and 5.3 A which is set by SCC to 12 Volt and 10 A to charge 70 Ah battery.

5.3 The Solar Thermoelectric Cooler Performance

To know the temperature variations of the thermoelectric cooling system is tested by placement of thermocouple sensors at multiple points in the cooler. The thermocouple sensor is located outside of the cooler for the ambient temperature, the top cover wall, the left wall, the right wall, the lower wall, and the cooled objects. The experiments conducted on starting at 09.00 WIB until 17.00 WIB for eight hours. The tests were performed for five days with varying weather conditions. Figures 4 up to 8 show the temperature distribution of the cooling wall and cooled objects during experiments.

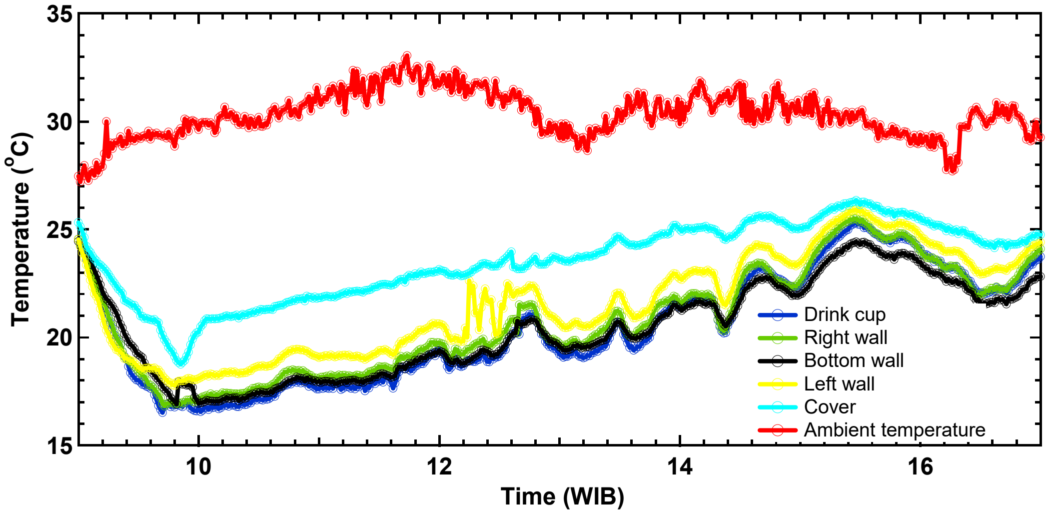

Figure 4. Temperature distribution in the cooler on the first day

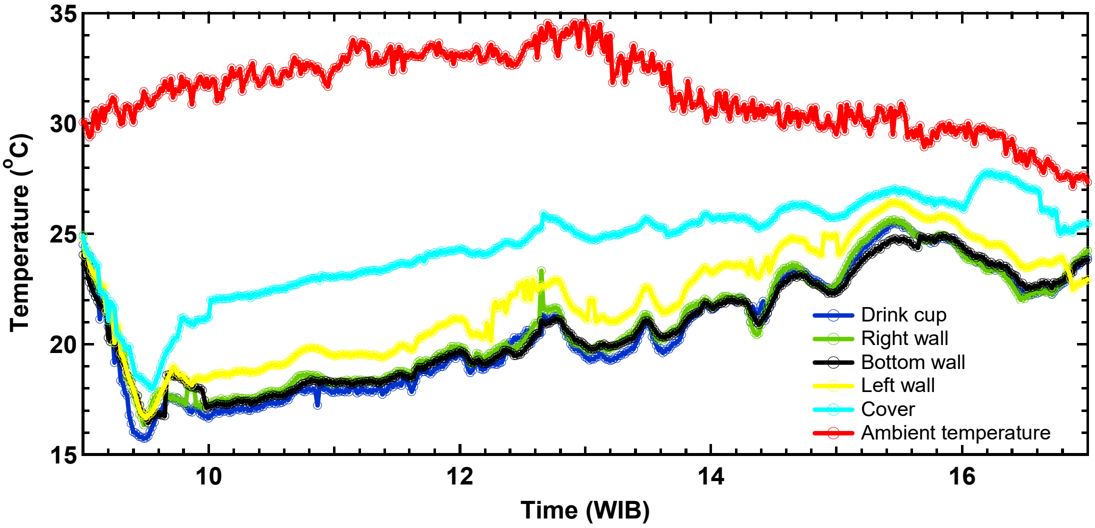

Figure 5. Temperature distribution in the cooler on the second day

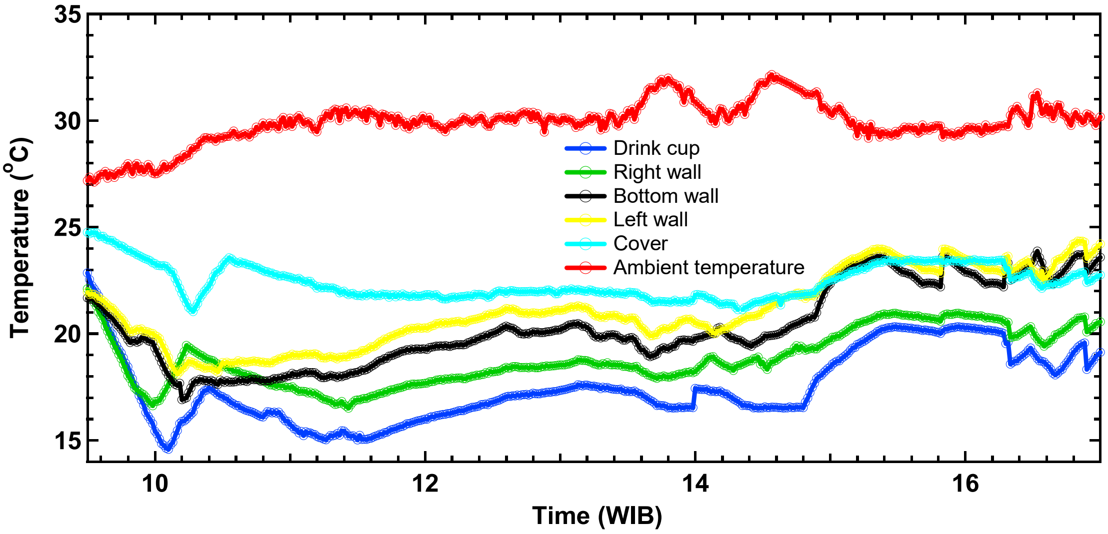

Figure 6. Temperature distribution in the cooler on the third day

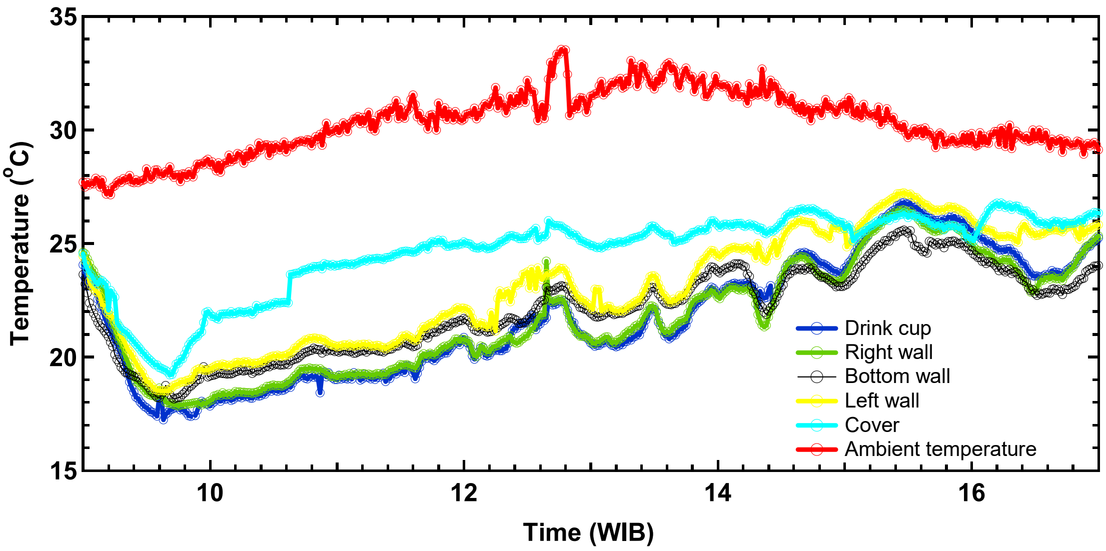

Figure 7. Temperature distribution in the cooler on the fourth day

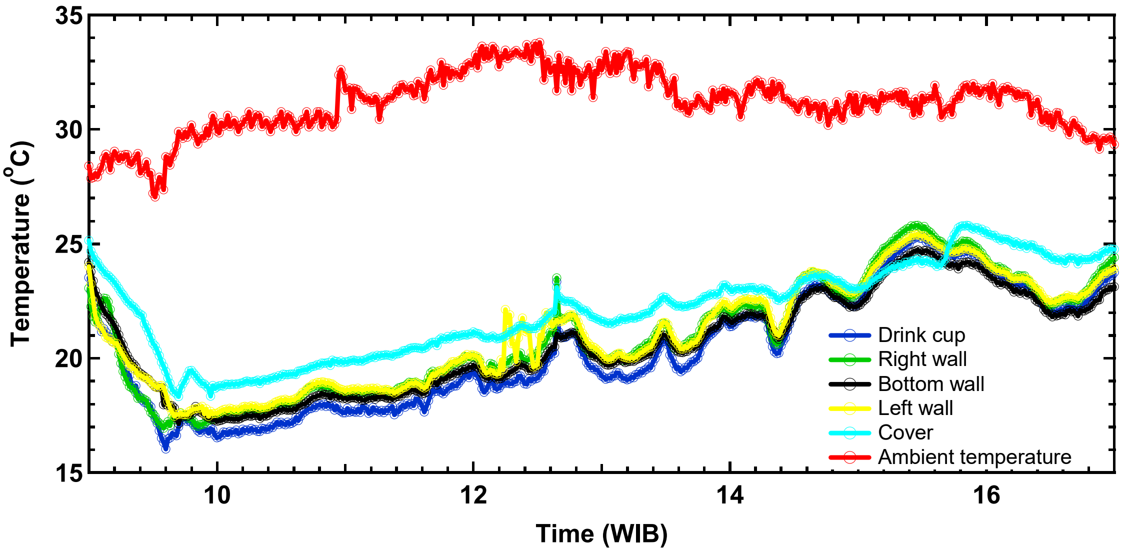

Figure 8. Temperature distribution in the cooler on the fifth day

Measurements are made on the inside and outside of the Peltier cooler system. The inside of the cooler box measured is the temperature on the left wall, the right wall, the lower wall, the top cover wall, and the drink cup. The outside is the outer top wall of the cooler box that directly experience exposure to sunlight.

During experiments, the minimum temperature of the drink cup was 16.51°C, 15.72°C, 14.57°C, 17.24°C and 16.03°C, respectively. The minimum temperature of the drink cup was obtained at 14.57°C on the second day with an average environment temperature of 31.34°C. Generally, the minimum temperature on drink cup is obtained at 09.15-10.00 WIB. The average temperature of the drink cup during the experiments was 20.30°C and 20.32°C. The inner wall temperature of the cooling box during tests ranges from 16-26°C. The measurement results show that the average temperature of the outside air on the first day until the fifth day is 30.54°C. The experimental data shows that the maximum air temperature achieved during the experiments was 33.79°C which occurred on the fourth day. In general, there is a difference in the temperature distribution that occurs at the point of the measured component. It can be seen from the figures 5 up to 8 that the temperature distribution on the upper wall is higher than the temperature distribution on the left, right, and bottom walls. This is influenced by the distance of heat sink components closer to the left wall, right and bottom. The experimental data shows that the measuring point on the outer wall of the cooler box has the highest temperature compared to the other measuring point which is caused by the influence of the air temperature and the effect of heat discharged by the fan from the heat sink attached to the surrounding environment. The results indicate that the temperature distribution in the cooler is quite evenly distributed to all sides of the cooler. This can be seen from the temperature difference between the measurement points ranging from 0.023-0.231°C. The difference in mean temperature inside and outside of the cooler is about 9-12°C. This condition indicates the process of heat dissipation contained in the cooler so that there is a cooling effect on the cooled object that drinks cup placed in the cooler. The experimental data also show that in general for five days of experiments there is an increase in temperature of the components measured in the cooler starting at 12.00 WIB. An analysis of the temperature increase in the cooler may be due to several factors. First, the rise in air temperature outside the cooler that also influences the temperature change condition inside the cooler. Second, the time operation of the fan long enough can lead to the emergence of heat in the cooling system. Third, the reduced power on the battery as energy supply to drive the fan and Peltier components on the cooler so that the thermoelectric element is not working optimally. The COP value of thermoelectric cooling box obtained during experiments as shown in table 2.

Table 2. The COP value during experiments

Day	Initial temperature (°C)	Minimum temperature (°C)	Cooling time (minute)	COP
1	26.77	16.51	53	0.190
2	26.76	15.72	40	0.356
3	26.95	14.57	55	0.213
4	26.86	17.24	49	0.209
5	26.78	16.03	47	0.254

The maximum COP value that can be obtained is 0.356 on the second day with a cooling time of 40 minutes. The average COP values obtained during the experiments is 0.245 and the cooling time to achieve a minimum temperature range from 40 to 55 minutes. The effect of weather conditions on the COP value is verified using a multiple regression analysis systems. The statistical analysis results show that the coefficient of determination (R^2) is 0.859, which means that the influence of weather conditions on the COP value is around 85.90%.

6. CONCLUSION

In the study, the solar thermoelectric cooling unit was made and tested. Cooling performance testing is carried out under bright outdoor conditions. It was found that the performance of the cooling system is very dependent on the intensity of solar radiation and the temperature difference between the hot and cold sides of the thermoelectric component. The maximum temperature difference between the cooling box inside and outdoor conditions is close to 19°C. The COP of the solar thermoelectric cooler, based on the material and technology available today is still lower than the cooling system that uses compressors. However, through several improvements, the solar thermoelectric cooling system will be acceptable in the future.

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