

Performance of a Thermoelectric Cooler Box Powered Using Solar Panels with a Mini Pin Fin Heat Removal Unit

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ABSTRACT

Experiments to investigate the performance of a thermoelectric cooler box powered using a solar panel with a mini pin fin as the heat removal unit was conducted at the un-condition ambient temperature. Due to solar power, the power given to the thermoelectric on different days was different. However, the power on the day of the experiment was nearly stable because the solar panel was connected to a battery. The parameters tested were the cooler box temperatures and COP (coefficient of performance) and there were four Cases examined in this study: Case A (the cooler box was empty), Case B (the cooler box was filled with water of 3000 ml), Case C (the cooler box was charged with 6000 ml of water), and Case D (the cooler box was filled with 9000 ml of water). For these experimental conditions, the maximum COP was 0.51. This was obtained for the run with 9000 ml of water. Increasing the water volume raises the temperatures inside the cooler box and the optimum performance is discussed.

1. Introduction

This study was performed due to the goods transportation requirements. The transportation of goods, blood and vaccines needs portable refrigerators. Thermoelectric (TE) cooler boxes seem like becoming an option. This was owing to the reports presented by previous researchers, e.g. [1-5]. The authors elucidated that the TE cooler box was much lighter, compact, no leakages, durable and easier to maintain. However, there is a limitation of this cooler type, namely low COP, even its COP is always less than 1. This indicates that studies in this field are still wide open to increase the COP.

Several researchers have been trying some ways to increase the TE cooler performances. The COP can be raised by advancing the quality of TE materials, differing the application procedures, and wangling the unit of heat dissipation. The research on TE materials is devoted to increasing the COP. Nevertheless, in terms of material, the TE development is slow. Good material for TE is indicated by its figure of merit. Bismuth telluride (Bi_2Te_3) is widely employed in TE generators and coolers for low temperature. Bi_2Te_3 possess a maximum value of $ZT \sim 1$ as reported in [6, 7]. According to the authors in [8], if the figure of merit can be increased to 2 or 3, the TE cooling can be cut-throat with compression systems. Furthermore, if the figure of merit is

as big as 6, then the TE cooling system can be used for cryogenic purposes. Due to the low development of TE material, increasing COP through applications has been becoming a choice. Some researches on the TE cooling application have been performed by several researchers, e.g. [1, 4, 5, 9]. However, the authors still obtained low COP (even less than 1). One parameter that can influence the COP of the TE cooling systems is the heat removal unit. In [10], the authors studied several heat removal units. They used heat removal units: a heat sink fin fan and a double fan heat pipe. Nevertheless, they still had a small COP.

Authors in [1] studied TE cooling using a mini channel and the power used to operate the TE cooling was a solar panel. They found that solar panel was promising power for the TE cooling system in the future. Furthermore, as electricity is expensive in several countries, e.g. Indonesia, renewable energy may be important to be applied. The good thing about using the solar panel is that this energy is free. Therefore, in this study, the energy used is generated using solar panels.

The theory of mini and microchannels has shown better heat transfer and more effectiveness. The studies of the micro and mini channels were conducted e.g. [11, 12]. The authors found that micro and mini channels could increase heat transfer. Nevertheless, again, in [1], the authors still obtained the COP of less than 1, although they already used a mini channel as the heat removal unit.

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Table 1: COP attained from available literatures related to the unit of heat dissipation

Referenses	Study	Heat removal unit	COP
[1]	TE cooler box powered using solar panels with a mini channel.	Mini channel	0.01-0.76
[10]	Experimental cooler box using two different heat dissipation units	Heat sink with fans Double fan heat pipe	0.002-0.02
[17]	Design and experimental solar TE refrigerator	Heat sink with fans	0.16
[18]	TE device for small scale space conditions	Heat sink with fans	0.43-0.45
[19]	TE refrigerator performance	Heat sink with fans	0.64

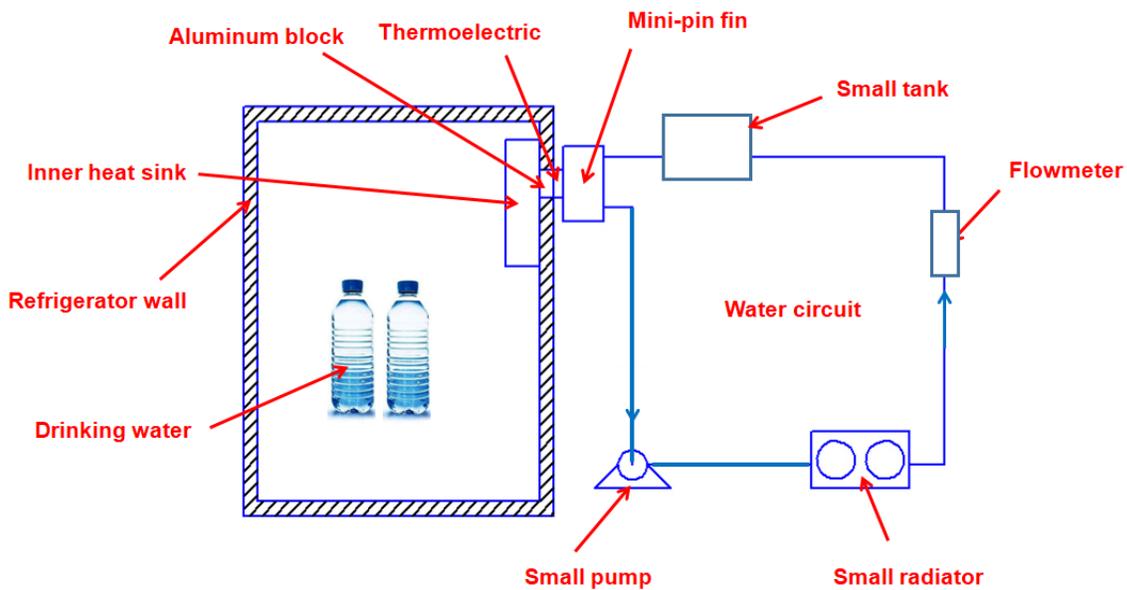


Figure 1: Schematic diagram of the apparatus

Because the COP gained in the previous study was still low, so this study tried using a mini pin fin. Studying mini or micro pin fin was ever conducted by several previous researchers, e.g. [13-15]. However, the authors in [16] stated that the mini pin fin could transfer high heat flux than conventional heat exchanger or mini channels. Owing to their encouragement, this current study used a mini pin fin as the heat removal unit. It was expected that the COP of the TE cooler box examined was higher than the COP obtained in the previous studies. This study was just to investigate the performance of the cooler box powered using solar panels with a mini pin fin as the heat removal unit. The study using a mini pin fin as a heat removal in a TE application has not been investigated yet. As shown in Table 1, none of the previous studies exposes the use of a mini pin fin as the heat removal unit at TE cooling systems. Hence, the novelty of this study is the heat removal unit that is constructed from a mini pin fin; it also contributes to the TE cooling system studies.

This study is a continuation of the previous study entitled performance of a large thermoelectric refrigerator power by a solar panel [1]. The difference in this study from the previous

study is the heat removal unit. In the previous study, the heat removal unit was constructed of a mini channel, while in this study the heat removal unit used was a mini pin fin.

2. Research Method

2.1. Experimental Set-up

This work is a part of TE cooling system studies using solar panels as power. This study is aimed to investigate the ability of a TE cooler run by solar panels with a mini pin fin as the heat dissipation unit, and to know the effect of water volume on the COP of the system. In the previous study, the heat removal unit was a minichannel, while in this recent study; the heat removal unit was a mini-pin fin. Nevertheless, the focus of this study was the performance of the TE cooler due to the heat removal unit. The study used a test rig shown in Figure 1. The test rig was also used in [1]. It consisted of a box, a TE, water, solar panels, a mini-pin fin, a pump, a radiator, a small tank, meter flow, a battery, a solar charger, and a data logger National Instrument (cDAQ-NI 9174). Similar to the previous study, all temperatures were measured utilizing thermocouples (K-type) that were calibrated in

an oil bath with an accuracy of $\pm 0.2^{\circ}\text{C}$, and the electrical power employed was assessed using a Vichy Vc8145 digital multimeter. The accuracy of ampere and volt measurement was 0.1% reading and 0.05% reading. Meanwhile, the water flow passing the mini-pin fin was calculated using FLR1000 flowmeter with an accuracy of ± 0.2 g/s.

As the electric current surges into the TE, the hot side temperature of the TE increased drastically. This increased temperature should be maintained so that it did not exceed 65°C , e.g. using water flow. If the hot side temperature was low, the cold side temperature was low too. That was why using TE as the cooler machine could be successful in cold countries because the environmental temperature was already low.

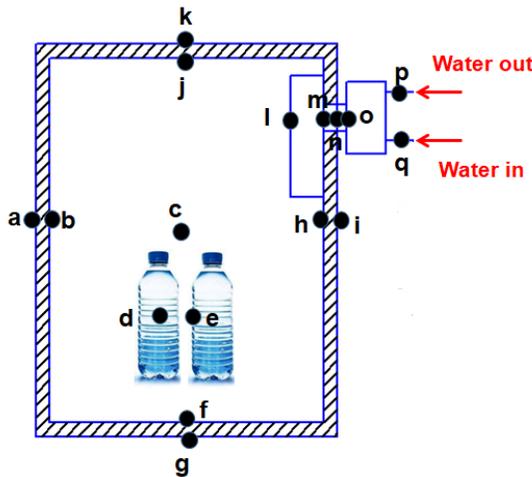


Figure 2: Thermocouple placements

Finally, the heat from the TE was taken away by the water flowing inside the mini pin fin towards the small radiator. The heat was then discharged from the small radiator into the ambient through a finned heat exchanger or radiator. Then the water came back to the small tank. The source of the electricity was solar panels; therefore, it fluctuated. When the sky was clear, the power

was large and vice versa. However, these fluctuations were eliminated by using a battery.

Thermocouple placements can be seen in Figure 2. Their locations are noted using the letters a-q. Meanwhile, the electrical flow diagram is presented in Figure 3. Two pieces of solar panels, each with 100WP power, were utilized and one free maintenance battery with a voltage of 12 V, and a current of 100 AH was employed. However, the analysis here was focused on the performance of the TE cooler only, while a depth analysis of the mini-pin fin and solar panel was not given in this study.

Parameters investigated were (1) heat absorbed by the TE (noted by Q_c), (2) the power is given to the TE noted, P_T , and (3) COP. The heat absorbed by the TE (Q_c) comprised of heat from the air, water and bottles inside the cooler box. The heat from the air can be predicted using equation (1). This equation can be found in [4, 10, 20]. The experimental uncertainties and conditions are listed in Table 2.

$$E_{a(i)} = m_a c_p (T_{(i-1)} - T_{(i)}) \quad (1)$$

E_a is the energy removed from the air inside the cooler box (J), m_a represents the air mass (kg), c_p is the specific heat ($\text{J}/\text{kg}^{\circ}\text{C}$) and T is the temperature of the air. To change the energy into the heat rate, eq. (2) can be used, this equation can be obtained in [1, 4-5, 20-21].

The cooler box size used was $0.317 \text{ m} \times 0.235 \text{ m} \times 0.447 \text{ m}$. The mini-pin fin was bought from an online shop and this was usually used in the CPU for cooling the processor. The variations of investigated parameters are Case A (the cooler box is empty), Case B (the cooler box is filled with bottles containing 3000 ml of water), Case C (the cooler box is filled with bottles comprising 6000 ml of water) and the last is Case D (the cooler box is filled with bottles consisting 9000 ml of water).

$$Q_a = \frac{\sum_1^n E_{a(i)}}{t_{(n)}} \quad (2)$$

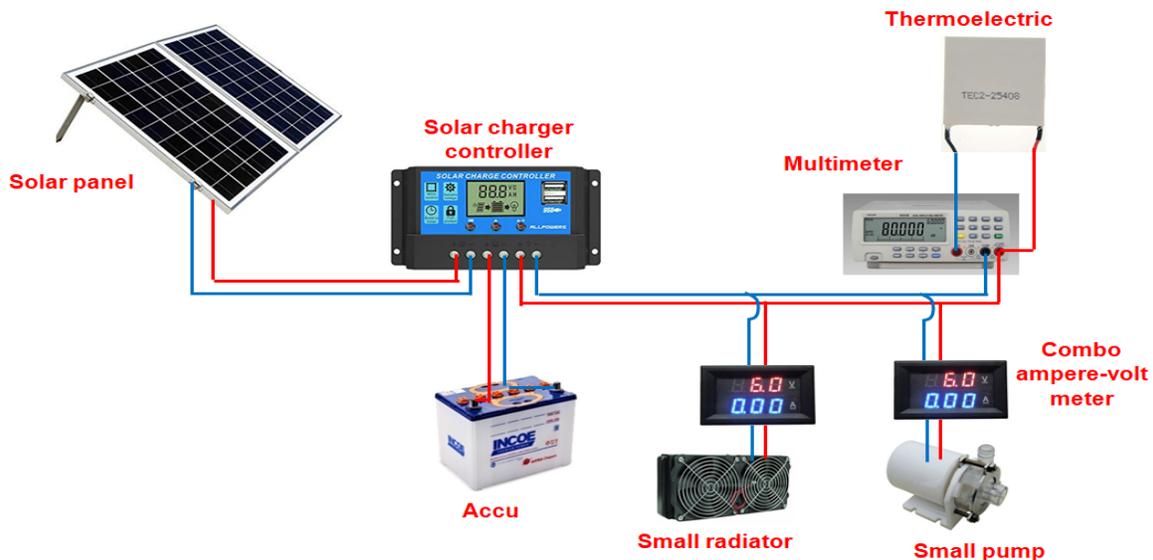


Figure 3: Electrical flow diagram

Table 2: Uncertainty and the operational conditions

No.	Parameter	Uncertainty	Range of measurements
1	Temperature (T)	$\pm 0.2^\circ\text{C}$	$9.42^\circ\text{C} - 48.75^\circ\text{C}$
2	Cooling capacity (Q_c)	$\pm 0.12\text{ W}$	$2.70\text{ W} - 20.63\text{ W}$
3	Power input (P_T)	$\pm 2\text{ W}$	$52.74\text{ W} - 85.68\text{ W}$
4	Pump power (P_p)	$\pm 0.21\text{ W}$	$4.86\text{ W} - 9.65\text{ W}$
6	Power input for system (P_s)	$\pm 2.8\text{ W}$	$65.9\text{ W} - 100.7\text{ W}$
7	COP	± 0.01	$0.041-0.34$

Q_a is the heat rate taken from the air (W), t is the time of the running cooler box (s). The energy and the heat rates absorbed by the TE from the water and bottles also can be estimated using equations (1-2) by changing the subscript a to w and b . For water, the energy and the heat rate are noted as E_w and Q_w , while for the bottles, they are designated as E_b and Q_b . Despite Q from air, water and bottles, Q also came from the ambient through the cooler box walls. This type of heat rate is called the conduction heat rate.

$$Q_k = kA \frac{T_{wo} - T_{wi}}{L} \quad (3)$$

where Q_k is the conduction heat (W), A is the heat transfer area (m^2), L is the wall thickness (m), T_{wo} and T_{wi} are the outer and inner wall temperatures ($^\circ\text{C}$). The total heat rate is noted by Q_c , it is the cooling capacity (W). Q_c is expressed in equation (4), which can be found in Changel and Boles [22].

$$Q_c = Q_a + Q_w + Q_b + Q_k \quad (4)$$

Then the COP is the performance of the TE cooler box that can be expressed as

$$COP = \frac{Q_c}{P_T} \quad (5)$$

$$COP_s = \frac{Q_c}{P_s} \quad (6)$$

COP_s is the coefficient of performance based on all powers supplied to the experimental system. P_T is power flowed to the thermoelectric module (TEM) in watt, in the experiment it was measured directly using a multimeter. P_s is the total power given

to the experimental system such as power for TEM, pump and heat exchanger. All powers required were measured directly. The TE specification used in this study is shown in Table 3.

Table 3: TEM specification

Model	TEC2-25408
Voltage	15.54V
Vmax (V)	15.4V
Imax (A)	8 A
Qmax (W)	65 W

3. Results and Discussion

Experimental results of a TE cooler box performance are presented in the form of graphs. Some recorded temperatures of air, water and bottle are reported in Figure 4. Figure 4 indicates that the ambient temperature increases for all Cases. This phenomenon was due to the time of experiments. The experiments were conducted from 9 o'clock until 12 o'clock local time. Therefore, the ambient temperature increased because the sun elevates with time. At the same time, the ambient temperature was not conditioned. However, the air temperature inside the cooler box for Cases A and B decreased with time, while for Cases C and D remained constant. For Cases C and D, the cooler box could no longer decrease the temperature inside. This was due to the performance of the cooler box. Increasing the volume of water inside the cooler box, the cooler box could not decrease the water temperature further. For Cases A and B, the phenomenon was also found in the previous studies, e.g. [1, 4-5, 19].

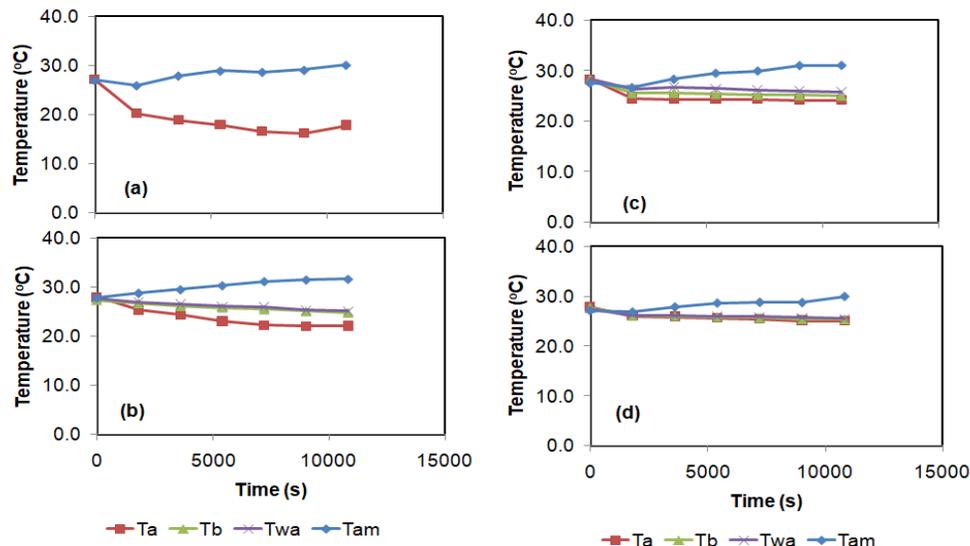


Figure 4: Recorded temperatures of air, water, and bottle inside the cooler box; (a) Case A, (b) Case B, (c) Case C, and (d) Case D

The increased ambient temperature affect greatly the cooling value. The estimated cooling value Q_c is presented in Figure 5. For all Cases, the Q_c increased with time. This was due to the presence of the conduction heat transfer from the ambient to the inner box through the cooler box walls. Increasing the ambient temperature levelled the difference temperature between the inside and ambient temperatures. Using equation (3) the obtained conduction heat rate increased. The increased conduction heat rate was also found in the previous studies [1, 4-5]. When Q_c was dominated by the conduction heat transfer rate, then it increased with time. Nevertheless, in this study, the experiments were run until noon local time, while in [4], the experiments were conducted for 7 hours. Therefore, they found that after the maximum value, the Q_c was constant. The problem in this current study was that in the afternoon the sun was covered by the building and trees so that the experiments were stopped. Nevertheless, Q_c could not be compared because that was obtained on different days as the cooler box was operated using solar panels. The reason for this was the power given to the system. It could be different on different days.

Another parameter investigated in this study was the COP. Although COP was obtained on different days, it could be compared because COP was cooling capacity per 1-watt power given to the TEC module, see equation (5). The relationship between COP and observation time is presented in Figure 6. The trend of the COP was different from that obtained by researchers in [4]. In [4], the ambient temperature remained constant, it did not increase and the COP increased and then after the peak, it decreased. In this study, the COP did not achieve the maximum value yet. However, Case D had the highest COP. The average COP of Case D was 0.51. Increasing the water volume elevated the COP. Comparing the COP of this study and the previous study indicated that using mini-pin fin got a lower COP than using a mini channel. This comparison did not agree with the results concerning mini and micro pin fins in [13-16]. Nevertheless, the problem, as explained above, was due to the imperfect placement of the mini pin fin. Also, in the previous study, the size of the mini channels was a bigger little bit.

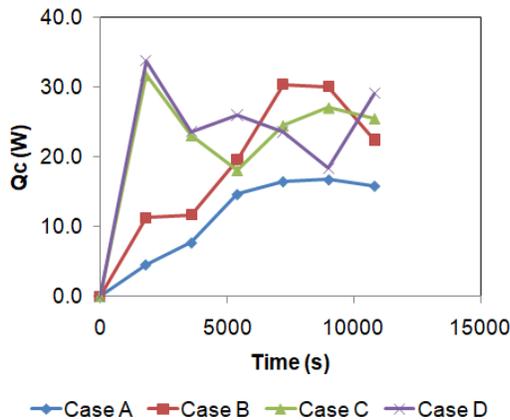


Figure 5: Relationship between Q_c and observation time

Additional data given in this study were the performance of the mini-pin fin, which was indicated by the mini pin fin efficiency. The experimental mini-pin fin efficiencies were found ranging from 82% - 93%. The efficiency was important to be

reported in this study to know the performance of the mini-pin fin. Those efficiencies were already good, however, the mini-pin fin installation was not perfect. It was difficult to instal the mini pin fin perfectly on the hot side surface of the TEC because between the mini pin fin and the hot side of the TEC, a thermocouple should be placed to measure the hot side temperature of the TEC.

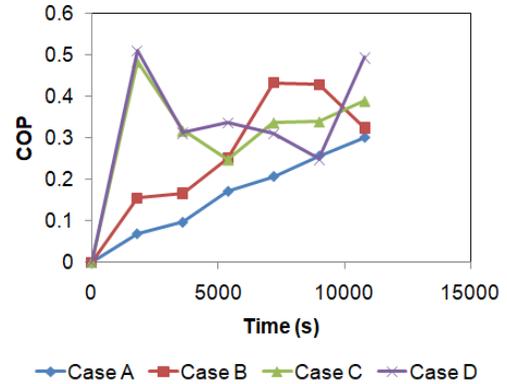


Figure 6: Relationship between COP and time

As the cooler box was run using solar panels, the recorded solar power was presented in Figure 8. Solar power, in general, increased with time. This was a similar trend to the Q_c and COP. This was due to the sun that rose along the time, especially in this study, the experiments were conducted from 09.00 to 12.00 local time. However, at midnight local time, all recorded solar powers decreased. This phenomenon was due to surrounding conditions. The solar panels were placed near the building and trees so that starting at 11.30 local time, the solar power panels were shaded. This was also the reason for the short time of running experiments. Due to the sun shaded, the experiments were stopped at 12 local time.

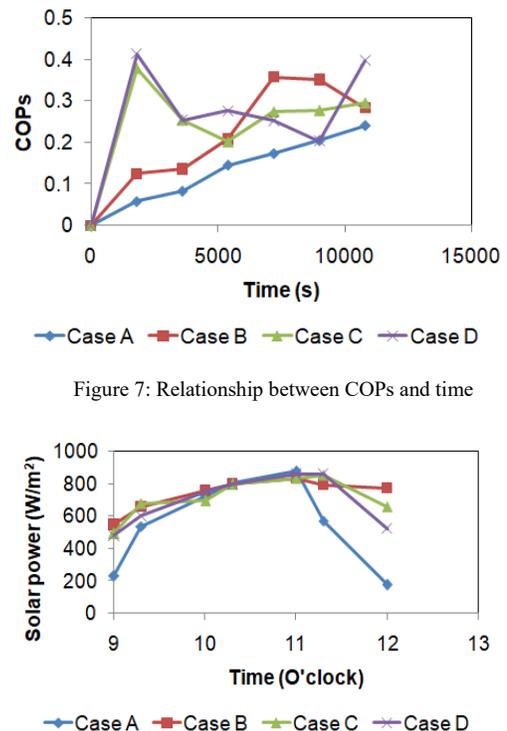


Figure 7: Relationship between COPs and time

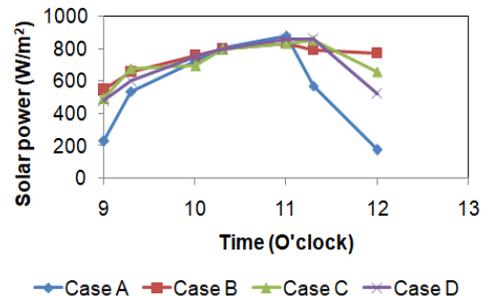


Figure 8: Relationship between solar power and observation time

4. Conclusion

A continuation study to assess the performances of a TE cooler box powered using solar panels with a mini pin fin as the heat removal unit was performed. Increasing the water volume raises the COP and the cooler temperatures. The optimal performance of the TE cooler box is Case B. COP increases with time for these experimental conditions. COP is lower than that obtained using the mini channel heat removal unit in the previous study. The maximum COP is 0.51 and the lower temperature obtained is 18°C. The lower COP is due to the imperfect placement of the heat removal unit. Further experiments need to be conducted to clarify the performance of the mini-pin fin in transferring heat. The parameter that can be compared is COP, but not the others. The solar panels are adequate to power the TE cooler box.

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Nomenclature

A	heat transfer area, m ²
COP	coefficient of performance
c_p	heat capacity, J.kg ⁻¹ .°C ⁻¹
E	energy, J
i	segment
n	end of segments
I	current, A
k	thermal conductivity, W.m ⁻¹ .°C ⁻¹
L	wall thickness, m
P	power, W
Q	heat, W
t	time, s
T	temperature, °C
TEC	thermoelectric cooler
V	voltage, V

Subscript:

a	air
am	ambient
b	bottle
c	cold side
wi	inner wall
wo	outer wall
k	conduction
p	plastic
s	system
T	power to TEM
w	water