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Modified Thermoelectric Coolers (TEC) Peltier Plate for Outdoor Activities with Rechargeable Battery using Solar Panel

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Abstract: Thermoelectric cooler box was designed with the purpose of cooling with thermoelectric cooler (TEC) Peltier plate as a cooling medium. The objective of this project was to invent a cooler box that is suitable for outdoor activities. The thermal conductivity which is to measure the ability of the material to conduct heat in each layer inside the thermoelectric cooler box was identified for heat transfer analysis. Thermoelectric cooler box can be operated with a 12V battery or 12V DC power supply. The battery power can be charged using a 20W solar panel (if the battery power is drained out), with the condition that there should be heat radiation to generate electricity. Thus, no additional cost is needed on ice cubes whereby previously it requires more ice cubes to maintain the cold temperature inside the cooler box. By using a Peltier plate, the cooling hours inside can reach up to 100,000 hours with a maximum of 12 can of beverages stored inside the cooling box. Based on literature reviews, conduction and convection resistance between each layer of materials inside the cooler box play an important role to ensure heat is transferred inside the box. The heat sink also helps to ensure heat dissipation before flowing into the cooler box. In this design, a total of 56 kW of heat can be transferred from the box to keep the cooler box cool with the minimum temperature 15.6°C within a period of 35 minutes.

Keywords: thermoelectric cooler, Peltier plate, solar panel, rechargeable battery, cooler box

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1. Introduction

Coolers keep your food and beverages cold in two ways: either with ice to bring the temperature down, and/or through insulation to keep the temperature down. Various types of portable coolers have been designed to enable persons to keep food items such as canned beverages handy while traveling and engaging in various outdoor activities such as at the campsite, during the sports day and at the beach for picnic where a traditional electric refrigerator is not available. The traditional portable cooler was simply an insulated container/box used to keep foods and drinks cool for a long time. This cooler box is very useful and can be used by anyone for various purposes and uses.

Generally, the existing cooler box used for outdoor activities uses ice cubes as its cooling material to keep the cooler box cool. Ice cubes are most commonly placed in cooler box to help the contents inside stay cool. Ice packs are sometimes used, as they either contain the melting water inside, or have a gel sealed inside that stays cold longer than plain ice. However, the ice will melt after a few hours and it needs to add more ice to cool the box. Besides that, the melting ice is likely to cause damage to the stored food if the food packaging is made of paper. There is also mini fridge portable refrigerator cooler box. The fridge uses thermoelectric cooling system to keep the drinks cold. The fridge can be plugged into the cigarette lighter outlet socket for immediate power source. However, the fridge cannot be left running in the vehicle overnight to charge the battery as it will run down the car battery.

In addition, there is also a portable cooler box that can be used for outdoor activities. It is light weight and the ice cube is replaced with cooler freeze pack to keep the cold temperature inside the bag. No more melting ice and damage to the packaging. The problem for this bag is when the cooler freezer pack is no longer cold, it has to be replaced with another cooler freezer pack.

From all the problems listed from the existing products, solution is needed to solve the problems. Therefore, planning has been made to modify a cooler box with thermoelectric coolers Peltier plate with rechargeable battery using solar panel so that it can be used for outdoor activities such as for picnic and camping. In this research, a cooler box will be designed with some modifications and then fabricated by using thermoelectric cooler (TEC) plate as cooling medium. In addition, the cooler box uses a rechargeable battery that can be charged using solar energy.

Thermoelectric devices can be split into two categories as thermoelectric generators (TEGs) and thermoelectric coolers (TECs). TEGs transform heat into electricity owing to the Seebeck effect[1]. On the other hand, TECs dissipate heat from a medium by using electricity through the Peltier effect [2]. The Peltier effect is a phenomenon whereby heat is dissipated or absorbed when an electric current flows across a junction between two materials.

From the previous research, Ruzaini [3] fabricated thermoelectric cooler and study of thermoelectric cooling module system and run some experimental procedures using three different sizes of cooler boxes for outdoor activities. The box used battery for the power supply. From the experiment, the temperature in the box maintain around 10°C to 12°C with coefficient of performance (COP) of 0.3. Meanwhile, Remeli [4] has also designed and built mini thermoelectric Peltier cooler using foam box and were used to validate the theoretical thermal resistance model. The system was powered by 12V and 6A power adapter. This cooler was able to lower cooler box temperature down to 18.5°C with COP of 0.5, which a little bit higher from the result from Ruzaini[3]. S. Manikandan et.al, also used TEC plate but he used for building space cooling application and more plates are used which is as many as 24 plates are used to cool the space [5].

Reiyu has also conducted research using TEC plate but the research has been done on electronic cooling application [6]. In cooling application, TEC plate serves as a device for transporting heat from a surface that has a temperature higher than ambient. Instead of using battery and DC power source, Sivam used dual axes solar tracker to provide power to the Peltier plate and charging the secondary battery while Arduino Uno is used to sense the light and calculate exact angle for the rotation of solar cell [7].

2. Materials and Methods

For the methodology, this research is divided into three phases, which are design concept, manufacturing process and data analysis. At first phase, three designs have been proposed for this research. For the first design shown in Figure 1, only one Peltier plate has been used to cool the inside of the cooler box. The Peltier plate, heat sink, cooling fan and battery is located at the back of the cooler box. As for the second design shown in Figure 2, it still uses one Peltier plate but there is a difference where the heat sink and cooling fan is located at the top of the cooler box while the battery is located at the back of the cooler box. The third design as in Figure 3 uses two Peltier plates to cool the inside of the cooler box faster. The Peltier plate, heat sink and cooling fan are placed on the both

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side of the box so that the cold air will spread evenly inside the box. The battery is located at the bottom of the cooler box for the stability, as presented on Fig. 1-3.

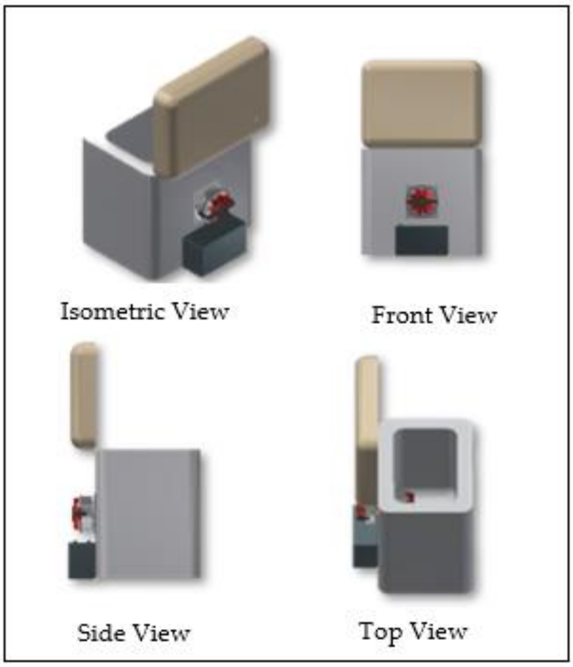

Figure 1. Design Concept 2

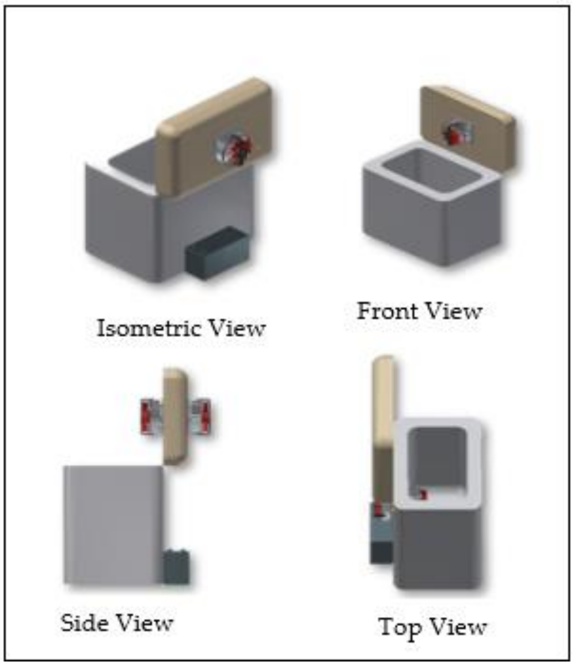

Figure 2. Design Concept 2

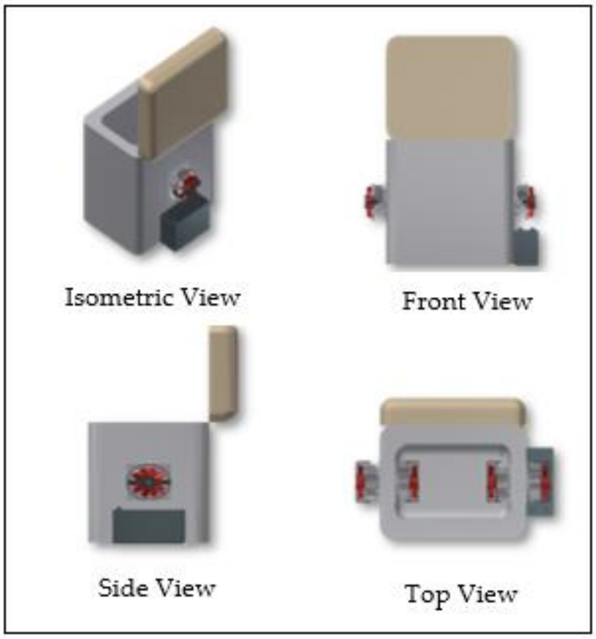

Figure 3. Design Concept 3

In the conceptual design phase, one design concept needs to be chosen which that will be carried in to the detail design phase. However, decision-making in the conceptual design phase lacks complete information and involves a large degree of uncertainties. These uncertainties are, for example, "the availability of new technology" or the actual performance and cost of a product developed from the selected concept. Engineers are forced to make a decision perceptually and based on their beliefs about uncertainties, as presented elsewhere [8]. The concept evaluation methods may be categorized into perception-based approaches and analytic approaches. In perception-based approaches, engineers quantify their perception by pairwise comparison scheme with Pugh's concept comparison and evaluation matrix or by perceptual ratings with Pugh's rating/weighting method [9].

Selection of design is a very important step in determining the outcome of a project. With this selection of design, the objective of the project can be achieved. In the selection of a project design, there is a feature or concept to be taken before carrying out of fabrication work on project. By using rating/weighing method as in table 1, all the proposed designs were rated and evaluated according to the criteria needed. In the table 2, it is found that the third design is the best design and is selected as the final design concept showed in figure 4, meanwhile figure 5 shows the actual prototype for the thermoelectric cooler box.

Table 1. Design evaluation matrix

Scale	1	2	3	4	5
Rate	Fair	Fairly good	Good	Very good	Excellent

Table 2. Design evaluation matrix

Evaluation criteria	**Design 1**	**Design 2**	**Design 3**
Rate of temperature	2	2	4
Weight of box	3	3	2
Suitable placement of TEC, heat sink, cooling fan and battery	3	2	4
Stability of the box	2	2	4
Total	**10**	**9**	**14**

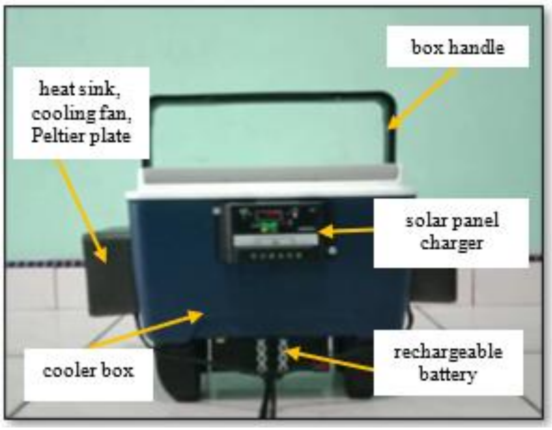

Figure 4. Final design concept

Figure 5. Actual product

At second phase, the manufacturing process is begun. This project is fabricated using 8L cooler box. The box material is made of high-density polyethylene while the insulation material is made of polyurethane. Some modification is made to the box by coating aluminum foil inside the box to

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maintain the cool temperature. The Peltier plate, heat sink and cooling fan is attached at the both side of the cooler box. Then the wiring is made to the 12V rechargeable battery and 20W solar panel.

The analysis in third phase is based on heat transferred from the Peltier plate to the box. The Fourier's Law of heat conduction and Newton's Law of cooling for convection have been used to calculate the heat transfer. Figure 6 shows the concept of heat transfer. Heat transfer is a discipline of thermal engineering that concerns the generation, use, conversion, and exchange of thermal energy (heat) between physical systems. Heat transfer is classified into various mechanisms, such as thermal conduction, thermal convection, thermal radiation, and transfer of energy by phase changes.

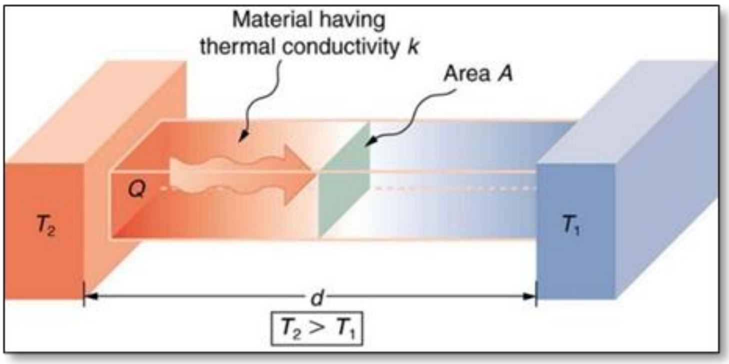

Figure 6. Heat transfer concept

The Fourier's law of heat conduction for the wall as in Figure 7 can be expressed as

$$\dot{Q}_{cond,wall} = -kA\frac{dT}{dx} \quad \text{(W)} \tag{1}$$

Remembering that the rate of conduction heat transfer and wall area A are constant as follows

$$\frac{dT}{dx} = constant$$

The temperature through the wall varies linearly with x. Integrating the above equation and rearranging yields, as on equation 2 and Fig. 7-8 [10].

$$\dot{Q}_{cond,wall} = kA\frac{T_1 - T_2}{L} \quad \text{(W)} \tag{2}$$

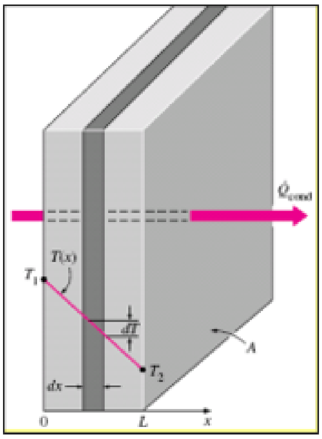

Figure 7. Fourier's law of heat conduction for the wall [10].

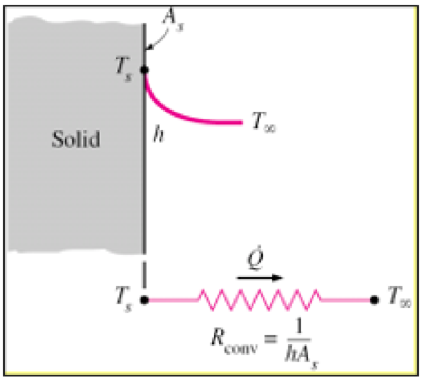

Figure 8. Newton's law of cooling for convection [10].

Thermal resistance can also be applied to convection processes. Newton's law of cooling for convection heat transfer rate $\dot{Q}_{conv} = hA_s(T_s - T_\infty)$ as in Figure 8 can be rearranged as equation 3.

$$\dot{Q}_{conv} = \frac{(T_s - T_\infty)}{R_{conv}} \quad \text{(W)} \tag{3}$$

where, R_{conv} is the convection resistance

$$R_{conv} = \frac{1}{hA_s} \quad (°\text{C/W}) \tag{4}$$

3. Results and Discussion

The box is tested for its application for one hour. The temperature is measured for every 5 minutes. From the observation depicted in Figure 9, the temperature is dropped from 28^{0}C to 15.6^{0}C within 35 minutes and maintain at that temperature until the battery is switched off. From the graph, it shows an unstable non-linear graph shape indicates that the cooling rate is not uniform. This is due to rapid cooling from the Peltier plate causes the liquid phase to be cooled below the melting point [11]. In addition, in this research, Peltier plates, cooling fans and heat sinks are located on both sides of the box thus the cooling performance increases rapidly as reported by Ahmed Al- Rubaye in his research, as on Fig. 9. He stated that the increasing of heat sink fan speed has improved the system performance, where it led to an increasing in heat absorbed by the cold side and the heat rejected from the hot side [12].

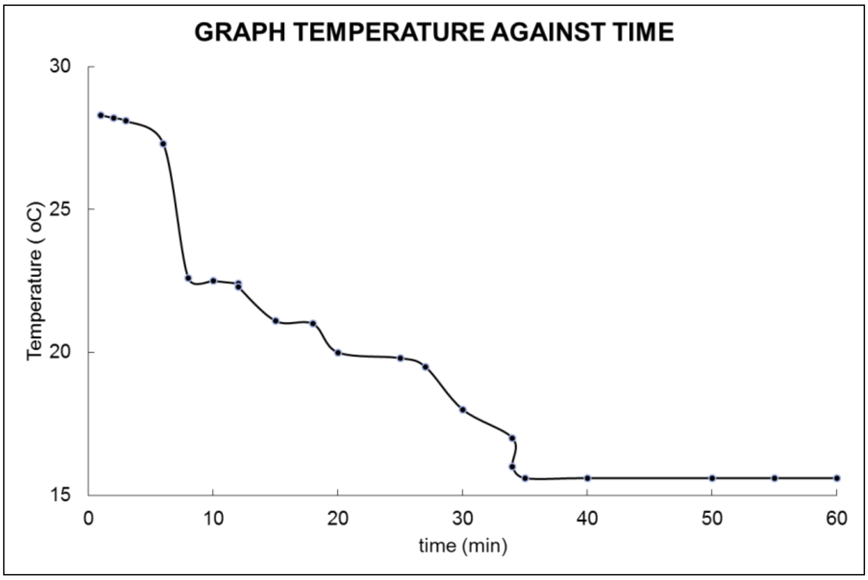

Figure 9. Graph temperature against time

Figures 10 shows the cross section of the side of the cooler box from the outside to the inside of the box. To calculate the heat dissipated from the box, each of the materials for the box needs to be identified so that the thermal conductivity can be determined.

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Figure 10. Cross section of the side of the cooler box from the outside to the inside of the box.

By using equation (2), the heat conduction between adjacent molecules of a material for the box is calculated. Then, the heat convection from the wall surface to the inside of the box is calculated. From the analysis, a total of 56kW of heat can be transferred from the box to keep the cooler box cool.

4. Conclusions

Thermoelectric cooler box can be operated with a 12V battery or 12V DC power supply. The battery power can be charged using a 20W solar panel (if the battery power is drained out), with the condition that there should be heat radiation to generate electricity. Thus, no additional cost is needed on ice cubes whereby previously it requires more ice cubes to maintain the cold temperature inside the cooler box. By using a Peltier plate, the cooling hours inside can reach up to 100,000 hours with a maximum of 12 can of beverages stored inside the cooler box. The conduction and convection resistance between each layer of materials inside the cooler box play an important role to ensure heat is transferred inside the box. The heat sink also helps to ensure heat dissipation before flowing into the cooler box. In this design, a total of 56 kW of heat can be transferred from the box to keep the cooler box cool.

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