Experimental study of a mini cooler by using Peltier thermoelectric cell

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Abstract. A 20 x 26 x 18 mm mini thermoelectric Peltier cooler was designed and built in this study. The Peltier thermoelectric cell was sandwiched between an external and internal heat sinks that acted to remove heat from the cooler box. When the Peltier thermoelectric cell connected to an external power source, the Peltier effect caused the heat from the refrigerator internal space to be conducted and removed to the ambient. The experimental data from this study were used to validate the theoretical thermal resistance model. It was found that the Peltier cooler was able to produce COP higher than 0.5 which the output was quite high compared to previous studies. This cooler was able to lower cooler box temperature down to 18.5 °C from the ambient temperature by removing 25W of heat. In the future, the validated theoretical model could be used to estimate the suitable design parameter such as the type of heat sinks, the size of the cooler, the cooling temperature and the cooler performance including the coefficient of performance (COP).

Keywords. Refrigeration; Peltier effect; Thermoelectric cooling; Cooler; Mini fridge

1. Introduction
In 1834, thermoelectric based on Peltier Effect was discovered by Jean Peltier, in which the direct current (DC current) applied across two dissimilar materials causes a temperature difference. It is found that when current flows across the intersection between two different wires, heat must be consistently added or subtracted to maintain the temperature. Peltier Effect in one of three effects that categorized in the thermoelectric system, where are Seebeck Effect and Thomson Effect. Thermoelectric modules use the variations in the energy levels of electrons to provide heat transfer. The energy is carried by the current between low energy level P-type semiconductors and high energy level N-type semiconductors from the cold surface to hot surface. The Peltier model is made of a serial connection of P-type and N-type elements. The Peltier effect is produced when electric current flows through two different types of semiconductor metals. The current starts to transfer heat from one side to other. The cold side of the Peltier module can be used as a cooler while the other side will continuously heat [2]. It is essential to cool the hot side to avoid the risk of damaging itself. Therefore, the Peltier must be combined with a cooler such as heat sink or water cooling to dissipate the heat of the hot side.
for effective operation. Figure 1 shows an example of a Peltier thermoelectric cell that consists of ceramic plates (cold and hot side) and the inner components such as P-type and N-type Peltier thermoelement.

![Thermoelectric module](image1)

**Figure 1.** Thermoelectric module [1].

Figure 2 demonstrates the heat that been absorbed from the cold side and rejected to the hot side of the thermoelectric cooler is connected to a power source.

![Structure and function of thermoelectric cooler](image2)

**Figure 2.** Structure and function of thermoelectric cooler [3].

There is numerous equipment utilize thermoelectric coolers that require heat removal from milliwatts to kilowatts. As the thermoelectric module is small and lightweight, the thermoelectric cooler also has been applied as part of outdoors, portable coolers, and cooling electronic components. The thermoelectric cooler also has been widely used with the increasing demand for computer components, mobile components, refrigeration and cooling system. The thermoelectric coolers likewise can cool computer systems to maintain their permissible temperature limit. There were several cooling systems developed to cool computer components such as CPU, chipset and other parts in order to shield them from overheating [4]. Thermoelectric cooling has been used due to its specialised; very light and minimal size, quiet and vibration free operation, without long-term maintenance and operation with DC
current. Indeed, thermoelectric modules have been available for many years and their cost have decreased over time. Moreover, thermoelectric cooling could provide efficient heat transfer and dissipation with better temperature control capacity for electronic devices.

A thermoelectric cooler (TECs) can pump heat from a low-temperature heat source to a high-temperature using the Peltier Effect. Therefore, the TECs have been utilized for temperature controlling, cooling, and refrigeration purpose[5].

Furthermore, the Peltier cooler was used as a passive component for a cooling plate. For example, the Peltier device was used to heat and cool an alumina block which has high thermal conductivity and low electrical conductivity. Therefore, the presence of the Peltier device helps them in controlling the high-performance capillary electrophoresis (HPCE) in dissipating the heat produced. The heat dissipation characteristics then compared with natural convection and fan cooling forced convection [1]. The thermoelectric device function was to minimize the change in column resistance with the applied electric field by minimizing any change in the outside capillary wall temperature. The generated heat must be removed rapidly from the outside surface of the capillary. Ohm's law relationship is used to describe the distinctive techniques for cooling by examining the reliance of current on the connected field.

The Peltier cell can also control the temperature of passive components by exchanging heat from a cooling plate to the flowing air. The passive components including capacitors, transformer and coils generate heat and are cooled with a forced circulated cooling system. The cooling liquid collects heat from the components and transfers to an aluminium cooling plate. The Peltier cell fixed to the cold plate surface will remove the heat to the incoming flowing air [6].

The performance of the Photovoltaic system was proven to be improved by using the thermoelectric cell (TEC) [7]. The TEC cooler was integrated to form a PV-TEC hybrid system. TEC played a leading role in the PV-TEC system by reducing PV cell temperature, increasing system productivity, boosting power capacity and prolonging life. The technical efficacy of a hybrid PV-TEC solution existed when the power output from the system with the TEC was observed to be higher than the power output without the TEC system. Therefore it was concluded that the efficiency of the PV system can be enhanced by inserting the TEC device at the back of the PV module, thereby reduced the PV cell temperature thus increased the efficiency and power capacity of the overall PV system.

A study showed that the TECs became the main part for a new concept for a helmet. It could give continuous cooling and protects the user at the same time [8]. High temperatures refer to work environments above 35°C and over 32 °C production usually makes people feel tired, physical decreases and slows down reaction speed. Therefore, a study on the design of a new cooling helmet was made, where a helmet was cooled by thermoelectric cooling with a combination of air and water cooling. Prior to this, the different cooling method was utilized including using phase-change material (PCM) and other methods. However, existing helmets have unreasonable structural weaknesses, low cooling efficiency, and weak cooling effects. A new helmet was developed based on the principle of thermoelectric cooling, which at the same time can cool one's head and neck with reasonable structure and easy use. The new cooling helmet is mainly comprised of an air-cooled and a liquid-cooled refrigeration module (ARM and LRM), power module and micro-water pump. The ARM components were included in the first TEC and the LRM was inserted in the second TEC. Figure 3 shows the helmet structure.
Figure 3. Thermoelectric refrigeration helmet structure [8].

The thermoelectric refrigerator could also be integrated to cool a building space. It can be an alternative choice for conventional vapour compression (CVC) cooling systems, as it does not use any coolant, silent and compact tools. A modified pulse operation of the TEC was designed to cool the building space. In the cooler pulse operation, a single pulse was given as an input, but in a modified pulse operation, the thermal side heat transfer coefficient also pulsed along with the current pulse [9].

In the automotive industry, one of the key targets is to provide comfortable cabins by providing occupants with direct transmission of airflow control. Researchers had discussed the optimum design for thermoelectric car seat temperature control system (CSCC) to achieve better system efficiency [10]. The configuration of an air-to-air heat exchanger was taken into account for investigating CSCC's optimum design. This CSCC cooling system had shown a reduction in fuel consumption by about 0.5%. The Peltier effect creates a temperature difference between the two TEC surfaces by flowing electricity inside the cell. This produces a cooling and heating modes on their surfaces. These modes can be changed by reversing the current direction used. The TEC surfaces have both high temperature and low temperature can transform the device to function as a cooler in the summer and a heater in the winter.

2. Methodology

This study involved a theoretical modelling, constructing and testing of a Peltier thermoelectric cooler. Figure 4 shows a schematic diagram of the stipulated cooler. A mini thermoelectric cooler body was constructed with a foam box. The Peltier thermoelectric module consisted of an internal heat sink, a Peltier thermoelectric cell (TEC) and the external heat sink was located at the centre of the upper side of the cooler box. The installation started with the thermoelectric module sandwiched between two heat sinks and followed with the installation of two cooling fans on the heat sinks body. One of the heat sinks was installed to enhance the cooling of the box and the other one to give a greater effect of heat rejection.
The module was prepared so that the internal heat sink was in the cooler box, the TEC was in the middle and parallel to the wall and the external heat sink was exposed to the surroundings (refers to figure 4).

![Figure 4. Schematic diagram of the experiment model.](image)

Figure 5 shows the details installation of the Peltier cell, sandwiched with heat sinks and cooler fans. Screws and thermal paste were used to join each of them.

![Figure 5. Installation of the Peltier module with the heat sinks and cooler fans.](image)

Figure 6 displays the full assembly of the Peltier module to the foam box. The slotted area (the box wall opening area) should be perfectly fit with the shape of internal heat sink without any gap. Some heat loss may occur during the cooling process due to the unfitted condition of the slotted area with the assembly of cooling parts. Therefore, the slotted area has been attached with a heavy-duty tape to prevent the cooling parts from moving and for the gap insulation. The installation then continued with the wiring circuit to the power source as shown in figure 4.
Figure 6. A complete Peltier module assembled to the cooler box.

The system was powered by a power adapter of 12V and 6A. After the power adapter switched on, the temperatures of internal space, $T_{int}$, and the TEC surface temperatures, $T_h$ and $T_c$ were measured. Since the experiment was conducted in an open environment, the temperature of the ambient was also recorded. The temperature measurements for both data were logged for every 5 minutes. To get a stable temperature reduction in the internal cooler box, the experiment was conducted for four hours long.

Figure 7. TEC 12706 Peltier module.

Figure 7 shows the thermoelectric cooler module that was used in the experiment. Generally, the specification for the module can be obtained from a supplier as shown in table 1.
Table 1. Peltier module characteristic.

| Peltier model (TEC 12706) | Description |
|---------------------------|-------------|
| Maximum current, $I_{\text{max}}$ | 6 Ampere |
| Maximum voltage, $V_{\text{max}}$ | 15.4V |
| $Q_{\text{max}}$ | 63 Watt |
| Maximum temperature difference, $\Delta T_{\text{max}}$ | 67 °C |
| Number of the thermocouples, $n$ | 127 |
| Material | Aluminum Oxide |
| Thickness | 0.0038 m |
| Length | 0.04 m |
| Width | 0.04 m |
| Seebeck coefficient ($\alpha$) | $\alpha_p = 2.2 \times 10^{-4}$ V/K $\alpha_n = 2.2 \times 10^{-4}$ V/K |
| Electrical resistivity ($\rho$) | $\rho_p = 1.2 \times 10^{-2}$ Ω cm $\rho_n = 1.2 \times 10^{-2}$ Ω cm |
| Thermal conductivity ($k$) | $K_p = 1.62 \times 10^{-2}$ W/cmK $K_n = 1.62 \times 10^{-2}$ W/cmK |
| Geometric factor, $G_e$ | 0.12 cm |
| Length of element, $L_e$ | 0.2 cm |

3. Theoretical analysis

Figure 8 shows the illustration Peltier cooler module from the side view of the position in which the temperatures were measured during the experiment. Internal temperature ($T_{\text{int}}$) is the temperature in the foam box.

![Figure 8. Illustration model from the side view.](image-url)
External temperature (Text) is the temperature outside of the foam box which is also as the ambient temperature. Cold temperature (Tcold) is the cold side of the thermoelectric module plate whereas hot temperature (Thot) is the temperature on the hot side of the thermoelectric module plate. Figure 9 shows the thermal resistance model for the Peltier model.

![Figure 9. Thermal model of the Peltier cooler.](image)

The resistance value was referred to [11] as it has the same characteristics as the heat sink used. All of these values were obtained to calculate the coefficient of performance (COP) of the Peltier cooler. The equations needed for the COP calculation are as follows [11]:

Area of the thermoelectric element;

\[ A_e = g_e X L_e \]  

(1)

The internal resistance of the couple;

\[ R_e = \frac{\rho L_e}{A_e} \]  

(2)

The thermal conductance;

\[ K_e = \frac{k A_e}{L_e} \]  

(3)

The figure of merit;

\[ Z = \frac{\alpha^2}{\rho k} \]  

(4)

Amount of current;

\[ I_o = \frac{V_a - \alpha (T_h - T_c)}{R_e} \]  

(5)

From these equations, all guessing values which are the Th and Tc can be calculated by the equation (6) and equation (7) by using iteration method. As referred to [11], the overall thermal resistance for heat sinks can be referred to table 2.

| Resistance | Description |
|------------|-------------|
| R1         | 0.365 K/W   |
| R2         | 0.215 K/W   |

Table 2. Heat sink thermal resistance.
Therefore, from the obtained value of $T_h$ and $T_c$, the coefficient of performance (COP) can be calculated using the following formulas:

$$\frac{T_{int} - T_c}{R_1} = n \left[ \frac{V_0}{n} - \alpha(T_h - T_c) \right] - \frac{1}{2} \left[ \frac{V_0}{n} - \alpha(T_h - T_c) \right]^2 R_e - K_e(T_h - T_c)$$

(6)

$$\frac{T_h - T_{ext}}{R_2} =$$

$$\frac{T_{int} - T_c}{R_1} + n \left[ \frac{V_0}{n} - \alpha(T_h - T_c) \right] \left( T_h - T_c \right) + \left[ \frac{V_0}{n} - \alpha(T_h - T_c) \right]^2 R_e$$

(7)

Therefore, from the obtained value of $T_h$ and $T_c$, the coefficient of performance (COP) can be calculated using the following formulas:

$$Amount \ of \ heat \ absorbed, Q_c = n[\alpha T_c l_a - \frac{1}{2} I_0^2 R_e - K_e(T_h - T_c)]$$

(8)

$$Input \ power, W_o = n[\alpha l_a(T_h - T_c) + \frac{1}{2} I_0^2 R_e]$$

(9)

$$COP = \frac{Q_c}{W_o}$$

(10)

For experimental analysis, the temperature of Peltier cell surfaces was measured to determine the $T_h$ and $T_c$ directly. Assuming the voltage and current as of the actual values, the actual results were calculated and compared with the theoretical analysis.

4. Results and Discussion

A thermoelectric cooler is usually used for temperature control tools, for example, scientific instruments for electronic and optoelectronic systems. Sometimes it is also used in precise temperature instruments for example to cool the laser temperature and infrared detectors. Therefore, it is very convenient to build small-scale thermoelectric cooling machines for these applications.

Therefore, in this study, we have constructed a mini thermoelectric refrigerator as shown in figure 5. The study also comprises of computer simulation using the governing equations 1-10. To illustrate the movement of energy from inside the cooler to the outside, a thermal resistance circuit had been illustrated in figure 9. The mini thermoelectric cooler contains an internal heat sink, a thermoelectric model and an external heat sink. $R_1$ and $R_2$ are the internal and external heat sink resistance.

To design a mini Peltier cooler, it is essential to know the design requirement such as the amount of heat removed from the internal heat sink, $Q_c$ and the external electric power, $W$ is to be applied to the TEC to flow the energy from a low temperature to a high temperature. The performance of the mini cooler is assessed by the coefficient of performance (COP). The COP is a function of $Q_c$ divided by the $W$. To calculate $Q_c$ and $W$, one need one needs to determine the $T_c$ (TEC cold surface temperature) and $T_h$ (TEC hot surface temperature). However, the value of $T_c$ and $T_h$ are not known initially because they depend on the design of all components.

The simulation routine was started by setting the design requirement of internal air temperature, $T_{int}$ and external air temperature, $T_{ext}$. Next was to assume a certain value of the temperature difference, $\Delta T$
between Th and Tc. Normally, the Th is set 15°C higher than the surrounding temperature to enable heat removal and Tc is 10°C lower than the internal air temperature. Others important property values need to be known to estimate the COP of the mini cooler are the electrical resistance of the TEC, Re and the thermal resistance of heat sinks, R1 and R2.

Equation (6) and (7) were iterated to determine a closer value of Tc and Th. The theoretical results were compared to the experimental data to ensure their validity. Based on the assumed temperature difference, ΔT, iterated Tc and Th, Re, R1 and R2, the COP could be easily estimated. Figure 10 shows the temperature change inside the cooler box. The temperature inside the box, Tint, took approximately 10 minutes to drop from ambient temperature, 30°C to 19°C. After that, the inner box temperature stabilized with an average temperature of 18.5°C. The temperature measurement was ended after 240 minutes.

![Figure 10. Ambient and ambient temperature versus time.](image)

When the TEC connected to the power supply, the current flow across a junction between two different wires of the TEC. This caused the heat to transfer from one side of the TEC surface to another due to the Peltier effect. Due to a sudden temperature drop to the TEC surface temperature, the heat from the cooler was conducted from a cold surface to the hot surface. As can be seen in figure 11, the cold surface temperature, Tc had dropped even lower temperature than the inner air temperature, Tint. Before reaching the steady state temperature, the TEC surface temperature plummeted to its lowest point of 8.9°C before reaching a steady state at approximately 9.5°C for more than 3 hours.

![Figure 11. TEC cold temperature versus time.](image)
Figure 12 shows the change of TEC hot surface temperature, $T_h$ with time. As can be observed that the $T_c$ took almost 50 minutes to reach a plateau. The theoretical $T_h$ had shown a good agreement with experimental data with less than 0.52% deviation. The theoretical average value of $T_h$ seems practical with 44.91°C which is 15°C higher than ambient temperature.

![Figure 12. TEC hot temperature versus time.](image)

Figure 13 displays the amount of external energy (electric power) needed to power the TEC and to cool the mini thermoelectric cooler down to 18.5°C from the ambient temperature. For the mini cooler of size 26mm X 20mm X 18 mm, it needed approximately 24.5 W to achieve the cooler temperature.

![Figure 13. Amount of heat absorbed by the TEC cooler.](image)

As shown in figure 14, the experimental result of the COP ranged from 0.524 to 0.531. The attainable COP in this study was found better than the typical COP output found in another study. The typical COP normally was found between 0.16–0.64 at operating temperature difference approximately $\Delta T=20^\circ C$ [12] [13]. The performance of the thermoelectric coolers depends on the effectiveness of the hot and cold side heat sinks. The COP could be refined by improving the module thermal resistances, thermal interface materials, and heat exchanger effectiveness.
5. Conclusion

A mini Peltier cooler was fabricated by using a thermoelectric Peltier cell coupled with fan-cooled heat sinks. The use of Peltier thermoelectric module has the big potential to replace the oversized conventional vapour refrigeration in designing a mini cooler for specific applications. The objective of this study is to design, fabricate and to validate a model of the mini thermoelectric cooler that operates in the actual conditions. This study consisted of modelling a theoretical background of the Peltier cooler to predict its performance. The performance that had been assessed including the minimum achievable cold temperature, the rate of heat removal from the refrigerated space and coefficient of the performance of the cooler. For the theoretical modelling, the temperature difference between the internal space of the cooler box and the ambient were firstly assumed. The assumed value was used in the simulation to predict the hot and cold temperatures of the Peltier cell surfaces. This value is essential in predicting the Peltier cooler performance such as the coefficient of performance (COP) and the heat removal from the mini cooler.

The study was followed by designing, fabricating and testing of the mini cooler prototype. For the actual testing, the ambient temperature, the internal and external air temperatures of the foam box and hot temperature and cold temperature of the plate were measured. The experimental data gathered in the testing were used to validate the theoretical model. It was found that the error between the experimental and simulation data were less than 1% which ensured the validity of the model. The testing results showed that the internal cooler box temperature drops significantly more than 10°C from its original temperature before reaching a steady state temperature. Meanwhile, the measured cold surface temperature of the Peltier cell extremely slumped to lower than 9°C while the hot surface temperature peaked up to higher than the ambient temperature at 45°C. This big temperature gradient created across the thermoelectric cell surfaces showed the effectiveness of the Peltier effect. In term of performance, the mini cooler was capable to remove approximately 25W of internal heat with 0.5 coefficient of performance (COP). The cooler COP was found above than the previous study by other researchers. There are few recommendations for future study could be made to enhance the mini cooler performance:

- To use better performance passive heat sinks for heat dissipation such as heat pipe heat sink.
- To use active cooling liquid heat sink for removing external heat from the Peltier module.
- To use high-performance Peltier cell.
- To use high conductivity thermal interface material for linking the heat sinks and the Peltier cell.
In the future, the validated theoretical analysis could be used to predict the suitable parameter such as the suitable heat sinks to be used, the size of the cooler, the cooling temperature and the performance of the cooler including the coefficient of performance (COP).

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