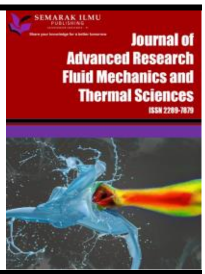
SEMARAK ILMU PUBLISHING

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage:
https://semarakilmu.com.my/journals/index.php/fluid_mechanics_thermal_sciences/index
ISSN: 2289-7879



Development of a Low-Cost Cooling Box Based on Thermoelectric Effect

Rosdi Ab Rahman[1,*], Mahmod Abd Hakim Mohamad[1], Masiri Kaamin[2], Mohd Faizal Mohideen Batcha[3], Mohammad Daniel Aiman Mazlan[1], Muhammad Luqman Rosli[1], Mohamad Azrul Arif Che Aziz[1]

1 Department of Mechanical Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Pagoh Education Hub, KM 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia
2 Department of Civill Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia (Pagoh Campus), Pagoh Education Hub, KM 1, Jalan Panchor, 84600 Panchor, Johor, Malaysia
3 Department of Mechanical Engineering, Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia (Parit Raja Campus), 86400 Batu Pahat, Johor, Malaysia

ARTICLE INFO

Article history:
Received 18 March 2022
Received in revised form 26 June 2022
Accepted 11 July 2022
Available online 3 August 2022

Keywords:
Thermoelectric; Peltier module; cooling; environmentally friendly

ABSTRACT

Among the well-established cooling method via thermoelectricity is Peltier effect. Often known as thermoelectric cooling, the cooling effect is achieved without the use of any refrigerant, and this holds several advantages for industrial applications. In this paper, the process of designing and testing of low-cost thermoelectric cooling box were addressed. The design process was elaborated and the main components in the system such as the Peltier module, fan, cooling box made from among others were detailed out. The developed cooling box was then tested experimentally in terms of cooling capabilities by using canned drinks as items to be cooled. It was found that the temperature reduction was notably fast and successfully provided cooling to the canned drinks. The low cost components and materials used suggests its economics and potentials to be used on the do-it-yourself (DIY) basis as a hobby as well as commercial use.

1. Introduction

Among the biggest issue in the world in the energy security. Billions of dollars have been invested annually by governments and private parties in researching and developing sustainable energy system to ease present energy consumption as well as reducing the environmental impact due the emission of greenhouse gases as a result of fossil fuel burning [1-2]. Thermoelectric cooling has its own advantages compared to traditional vapour-compression cooling systems. Among the advantages were no noise and vibration as no compressor is present the cooling system. Hence the inherent components such as electrical motor, bearing, belting, lubrication etc is also not required. Apart from that, thermoelectric cooling also has better temperature control and longer life-span. Among the industrial applications are medical cooling, electronic cooling and many more. However,

* *Corresponding author.*
E-mail address: rosdi@uthm.edu.my

https://doi.org/10.37934/arfmts.98.1.171176

due to the limited cooling capacity, the coefficient of performance (COP) is lower than that of vapour-compression cycles and this is among the opportunity for researchers to further improve the system [4-7].

In this paper, a low-cost the thermoelectric cooler was designed, fabricated, and studied in terms of its cooling performance. Apart from being relatively cheap, the cooler box was intended to be small, lightweight and portable so it can be used by small business owners like hawkers and for leisure use by travelers and those involved in recreational activities. Among the apparent advantage of the proposed cooler design is the ability to be powered by power supply from cars via built-in USB port which is a common accessory in modern cars.

1.1 Related Work

Peltier effect is created when there is a potential difference (temperature difference) of either high or low temperatures between different material intersections [7]. There was also another concept which is the Seebeck effect that also applies the concept of thermoelectric [8]. From the Peltier effect research, a cooling method designated as thermoelectric cooling was discovered and later developed. Thermoelectric cooling was found unique and useful because it can cool down an object without any moving pieces or other complex machinery that separates the cooler from its ambient surroundings [9]. The device that was created to take place for this type of method is the Peltier elements or thermoelectric coolers which also known as TECs [10]. The Peltier elements are just a basic module of thermoelectric cooling but they can be constructed into a far more complicated Peltier module device. These Peltier elements are connected to semiconductor materials [11]. As a result, the semiconductor materials are often used in the thermocouple of thermoelectric coolers such as the combination of Bismuth and Telluride [12]. These materials were constructed to come into contact with the radiator hot and cold side of the Peltier element. The cubes then were named the P and N-type semiconductors based on the free electrons in the cube [13]. The cubes with extra free electrons and which means mainly carry the negative charge elements were named the N-type semiconductors [14]. This Peltier element is compulsory for the project as the designated Cooling Box is using this component as the main cooling source. As of today, the applications of thermoelectric cooler or Peltier elements are quite big. All of these TEC modules are being used in military, medical, industrial, scientific, and laboratory, as well as telecommunications organizations [15].

2. Methodology

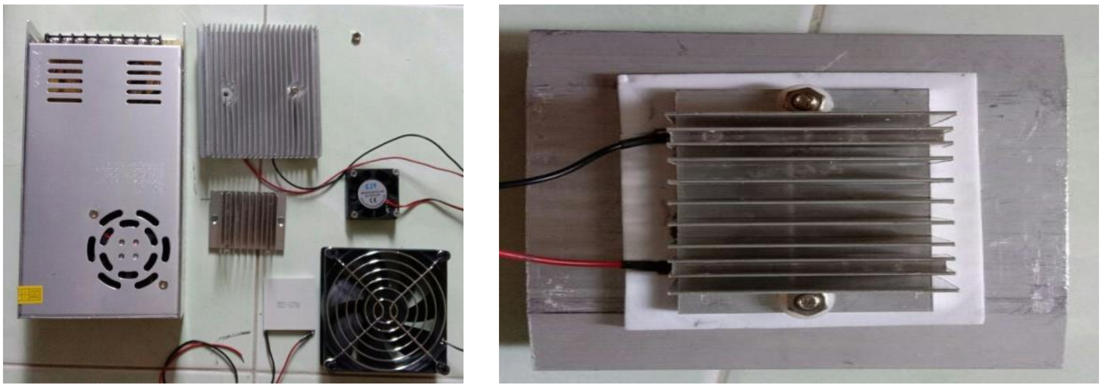
As stated earlier, the study embarks with the aim to design, fabricate and test a low-cost thermoelectric cooling box based on Peltier effect. Hence the study begins with identifying the main design needs which were mobility and cost efficiency. Hence the following section describes the materials used and also the method for assembling and testing the cooling box.

2.1 Materials

Peltier modules are exceptionally compulsory for this project which produce the cool thermal energy from electrical energy and cool down space in the polystyrene box. Two Peltier modules connected in parallel are being used to increase the product cooling capability. Then, the heatsink works as a heat transfer medium from the Peltier module to avoid the elements in the Peltier module meltdown because of the heat generated. Four heatsinks which consist of two small and two big heatsinks were used to transfer heat from the Peltier module inside and outside from both sides of the cooling box. Next, a polystyrene box is used as the main space to store the object that needs to be cool down as it is efficient to prevent the cool air heat loss from going outside of the cooling box. Then, the power supply is used as the main source of power or electrical energy to operate the product, which converts from DC to AC, and lastly producing AC for the product power source. There were four CPU fans used for this project. Same as the heatsinks, there were two small and two big CPU fans used as the heat dissipater to prevent any overheating of the component and spreading the cool air widely in the polystyrene box. The big CPU fans act outside the cooling box while the small CPU fans work vice versa. Then, the thermal paste is used as the adhesive medium to attach the Peltier module, heatsinks, and CPU fans while also can transfer the heat through all the components. Lastly, connecting wire is used as the connector for the loop of the electric circuit which connects the Peltier cooling elements to the power supply and the power supply to the electrical energy source through a plug.

2.2 Methods

The product's method or its assembly processes started with preparing all the main components used for the Peltier module assembly process as the Figure 1(a). Then, the next process is by placing or sticking the Peltier module hot side on the big heatsink using the thermal paste as the adhesive material while sticking the small heatsink on the cold side of the Peltier module using the screws and nuts as the Figure 1(b).



(a) (b)

Fig. 1. Main components (a) Power Supply, Heatsinks, Peltier Module and CPU Fans Preparation (b) Fastening Process for the Peltier Module between Small and Big Heatsink

The wiring and fastening process is primarily used in making this project's end product out of all the methods for producing the product. All of the wirings must be perfectly connected for the product to function properly and to avoid an electrical accident such as an electric shock. Then, the fastening process must be done well and on-point for all the components fastening position because sometimes a wrong arrangement of position for the components can affect the product's effectiveness and safety.

3. Results

As for the outcomes, a physical product was produced which is the Peltier-based thermoelectric cooling box as the Figure 2(a) and (b). Then, the functionality of the Peltier-based cooling box being tested by experimenting with it under some conditions and the data recorded will be discussed.

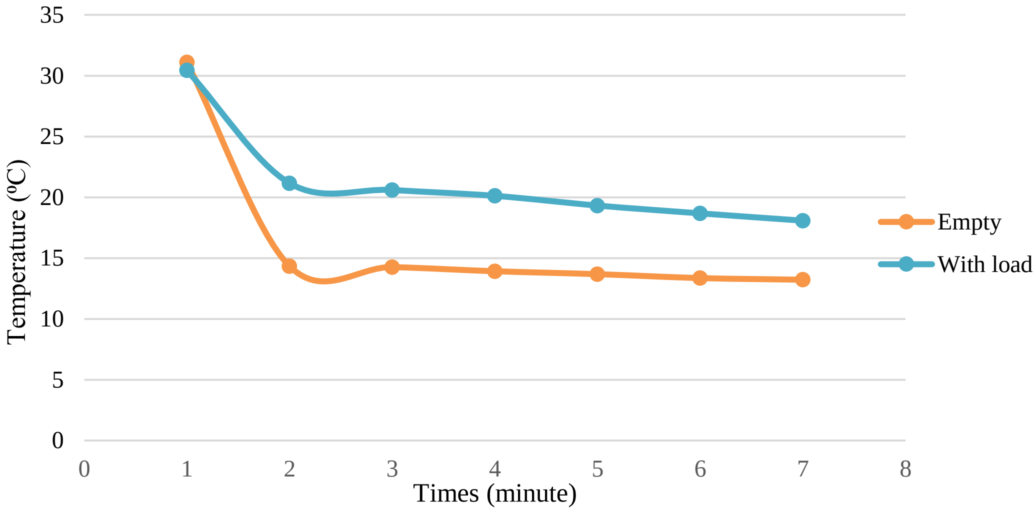
(a) (b)

Fig. 2. Peltier-Based Thermoelectric (a) Cooling Box Final Technical Drawing Design (b) Cooling Box Final Product Result

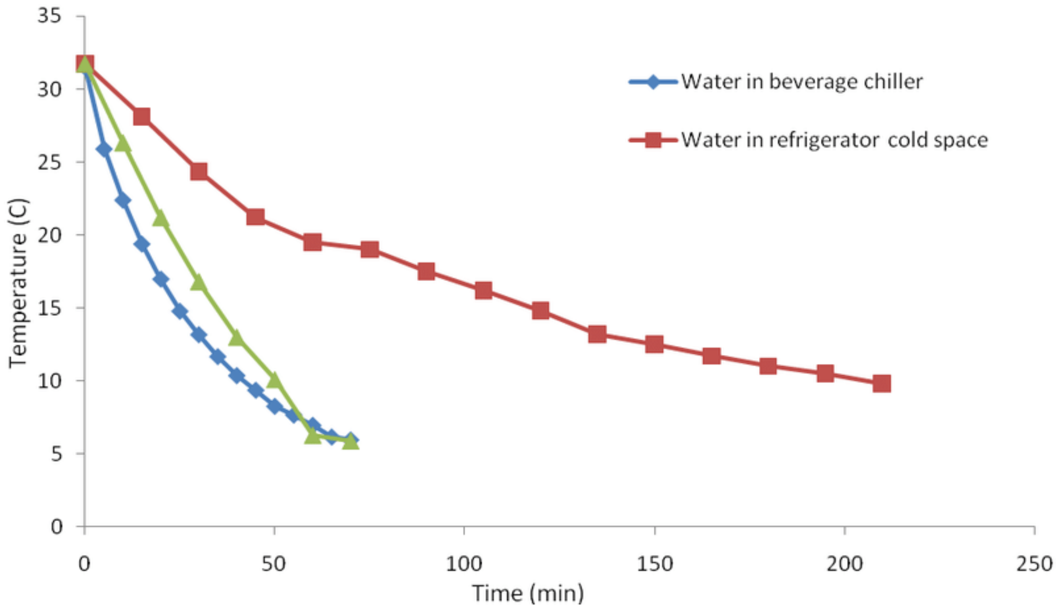
Two conditions are set for the experiment to test the cooling box functionality where the first condition is there is nothing in the polystyrene box while there are six canned beverages in the polystyrene box for the second condition. For both conditions, the temperature was recorded in the polystyrene box every 15 minutes starting from the initial polystyrene box temperature until it finally reaches 90 minutes. For each condition, five tests were conducted to find the average temperature to ensure that the experimental data is accurate.

3.1 Discussions

As shown in Figure 2(c) and (d), the cooling performance of the conventional refrigerator is undoubtedly great as the compressor and the gases inside the refrigerator could easily drop and constantly kept the temperature of the refrigerator below 13 ^{o}C. Not to mention, the mini cooling box also had a good cooling performance mainly in the early minutes of the cooling process. But the lack of gas and compressor that has been used in conventional refrigerators makes the performance start to drop slowly as the temperature starts to maintain at 18 ^{o}C after 90 minutes of cooling compared to the conventional refrigerator which can drop to 13 ^{o}C. Next, the power generated by the conventional refrigerator is greater than the mini cooling box as the Figure 2(c) and (d) shows that the refrigerator recorded a temperature of 17 ^{o}C after 90 minutes compared to the mini cooling box which was recorded just 18 ^{o}C after 90 minutes. The refrigerator might be the best choice to be the best storage for a long period but the mini cooling box can cool down the item stored inside of it quicker than the conventional refrigerator. This can be proved as the graph shows that the mini cooling box can drop about 10 ^{o}C in just 15 minutes of the cooling process. As for the similarity of data in both slopes in Figure 2(c), both of the slope patterns on the graph look identical. For the first 15 minutes of the experiment, the temperature dropped much for approximately an average of 9 - 17 ^{o}C while the temperature drops every 15 minutes after the first 15 minutes till the end did not drop much with only approximately an average of 1 - 4 ^{o}C. This shows that at some point of the experiment where the temperature dropped slowly, the thermal equilibrium process happened. Thermal equilibrium seems more obvious when there are canned beverages in the cooling box.



(c)



(d)

Fig. 2. Graph (c) Temperature versus Time Taken for Both Experiment Data (d) Temperature versus Time Taken for Water in a Refrigerator Cold Space [5]

4. Conclusions

In conclusion, the developed cooling box based on thermoelectric principle was successful. This is based on the ability of the cooling box to provide cooling effect to the tested product. The cooling box is suitable for various applications such as for small local businesses or mobile applications, or even off-grid application such as campers with integrating with small solar panel. The study also shows that the cooling box can designed using simple household or DIY components, which also can be used for demonstration among school children on the thermodynamic laws.

Acknowledgement
The authors would like to thank the member committee of TIER1 Grant (H811) partially sponsored by Universiti Tun Hussein Onn Malaysia and also team research Department of Mechanical Engineering, Centre for Diploma Studies, Universiti Tun Hussein Onn Malaysia.

References

[1] Mondal, Mithun, Djamal Hissein Didane, Alhadj Hisseine Issaka Ali, and Bukhari Manshoor. "Wind Energy Assessment as a Source of Power Generation in Bangladesh." *Journal of Advanced Research in Applied Sciences and Engineering Technology* 26, no. 3 (2022): 16-22. https://doi.org/10.37934/araset.26.3.1622

[2] Zakaria, Sazalina, Radin Diana R. Ahmad, Ahmad Rosly Abbas, and Mohd Faizal Mohideen Batcha. "Greenhouse Gas Emission Intensity Assessment for Power Plants in Peninsular Malaysia." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 88, no. 2 (2021): 14-26. https://doi.org/10.37934/arfmts.88.2.1426

[3] Choudhary, Vishwjeet, Manoj Kumar, and Anil Kumar Patil. "Experimental investigation of enhanced performance of pin fin heat sink with wings." *Applied Thermal Engineering* 155 (2019): 546-562. https://doi.org/10.1016/j.applthermaleng.2019.03.139

[4] Singh, Baljit Singh Bhathal. "Nor Amelia Shafikah Mat Noh, Muhammad Fairuz Remeli, and Amandeep Oberoi." Experimental Study On Waste Heat Recovery from an Internal Combustion Engine Using Thermoelectric Generator."." *Journal of Advanced Research in Applied Mechanics* 72: 25-36. https://doi.org/10.37934/aram.72.1.2536

[5] Budiyanto, Muhammad Arif, Alif Hikmah Fikri, and Hanmah Ayuningtyas. "Study on the application of thermoelectric coolers inside unmanned surface vehicles." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 82, no. 1 (2021): 12-20. https://doi.org/10.37934/arfmts.82.1.1220

[6] Ab Rahman, Rosdi, Mahmod Abd Hakim Mohamad, Masiri Kaamin, Mohd Faizal Mohideen Batcha, Mohammad Daniel Aiman Mazlan, Muhammad Luqman Rosli, and Mohamad Azrul Arif Che Aziz. "Experimental study of Peltier-Based Thermoelectric Cooling Box System." *Journal of Advanced Research in Applied Mechanics* 94, no. 1 (2022): 1-6.

[7] Saini, Anuradha, Rajesh Kumar, and Ranjan Kumar. "Introduction and brief history of thermoelectric materials." In *Thermoelectricity and Advanced Thermoelectric Materials* (2021): 1-19. https://doi.org/10.1016/B978-0-12-819984-8.00012-6

[8] Vining, Cronin B. "Thermoelectric properties of silicides." In *CRC handbook of Thermoelectrics*, pp. 277-286. CRC press (2018): 277-286. https://doi.org/10.1201/9781420049718

[9] Sonwani, Tarun Prasad, Ashish Kumar, Gulab Chand Sahu, and Kundan Lal Sahu. "Thermoelectric refrigerator using Peltier module." *International Research Journal of Engineering and Technology (IRJET)* (2020).

[10] Nesarajah, Marco, and Georg Frey. "Thermoelectric power generation: Peltier element versus thermoelectric generator." In *IECON 2016-42nd Annual Conference of the IEEE Industrial Electronics Society* (2016): 4252-4257. https://doi.org/10.1109/IECON.2016.7793029

[11] Kumar, Sumit, and Dhaneshwar Mahto. "Thermal Analysis and Performance Evaluation of Peltier Module." In *Renewable Energy and its Innovative Technologies* (2019): 173-184. https://doi.org/10.1007/978-981-13-2116-0_14

[12] Witting, Ian T., Thomas C. Chasapis, Francesco Ricci, Matthew Peters, Nicholas A. Heinz, Geoffroy Hautier, and G. Jeffrey Snyder. "The thermoelectric properties of bismuth telluride." *Advanced Electronic Materials* 5, no. 6 (2019): 1800904. https://doi.org/10.1002/aelm.201800904

[13] Nikolić, Radovan H., Miroslav R. Radovanović, Miroslav M. Živković, Aleksandar V. Nikolić, Dragan M. Rakić, and Milan R. Blagojević. "Modeling of thermoelectric module operation in inhomogeneous transient temperature field using finite element method." *Thermal Science* 18, no. suppl. 1 (2014): 239-250. https://doi.org/10.2298/TSCI130112185N

[14] Pravinchandra, Thakkar Mohit. "Peltier Cooling Module." PhD diss., PANDIT DEENDAYAL PETROLEUM UNIVERSITY, 2015.

[15] Zoui, Mohamed Amine, Saïd Bentouba, John G. Stocholm, and Mahmoud Bourouis. "A review on thermoelectric generators: Progress and applications." *Energies* 13, no. 14 (2020): 3606. https://doi.org/10.3390/en13143606