JCBI
Journal of Computing & Biomedical Informatics
ISSN: 2710 - 1606
Volume 06 Issue 02
2024
Research Article
https://doi.org/10.56979/602/2024

Experimental Investigation of Peltier Based Thermoelectric Cooling System for Vaccine Storage

Yousaf Khan[1*], Taimur Ahmed Khan[1], Muhammad Ilyas[2], Malik Taimur Ali[3], and Sheeraz Ahmed[3]

[1]Department of Electrical Engineering, University of Engineering and Technology Peshawar, Pakistan.
[2]Department of Biomedical Engineering, Baluchistan University of Engineering and Tech Khuzdar, Pakistan.
[3]Department of Computer Science, I*QRA* National University, Peshawar, Pakistan.
Corresponding *A*uthor: Yousaf Khan. Email: y.khan@uetpeshawar.edu.pk

Received: December 21, 2023 **Accepted:** January 12, 2024 **Published:** March 01, 2024

Abstract: Vaccines are typically administered during routine immunization programs, with a critical focus on maintaining a cold chain system. The cold chain system plays a pivotal role in ensuring the efficacy of vaccines. In this paper, a portable solar-powered vaccine carrier box based on the Peltier Effect for effective vaccine cooling is designed and experimented. The system is equipped with four 12V DC 3.5A Thermoelectric Cooler (TEC) Peltier Modules, with strategically positioned heat-sinks outside the cooling box. Additionally, the setup incorporates a 12V 180W Solar Panel for daytime power generation and eight Rechargeable Li-Po 3.7V 4500mAh batteries for uninterrupted operation for 3 hours. The experimentation involved three distinct conditions. Firstly, in the empty cooling box, a gradual temperature decrease was observed. Secondly, with the introduction of 10 sterile glass vaccine tubes filled with water, the temperature decreased more slowly, reaching 15°C in 62 minutes and 8°C after 90 minutes. Lastly, with 6 vaccine tubes, it took approximately 55 minutes to reach 15°C and about 90 minutes to achieve the desired 8°C temperature. The system exhibits a Coefficient of Performance COP of 0.42. The findings emphasize the effective cooling performance of the novel storage system, highlighting its ability to maintain temperatures below 15°C, a critical factor in preserving vaccines.

Keywords: Coefficient of Performance; Peltier Effect; Thermo Electric Cooling; Vaccine Storage.

1. Introduction

In the rural areas of Pakistan, infectious diseases cause a significant risk to the lives of infants and young children, leading to very high mortality rates and disabilities. The most economically efficient strategy for preventing these infectious diseases is through vaccinations. Vaccines are typically administered during routine immunization programs, with a main effort on upholding a cold chain system. This cold chain system significantly contributes to ensuring the efficacy of vaccines. It involves a proper management of cold storage and transportation of vaccines from the manufacturer to the patient, within a specified temperature range [1].

The conventional cold storage systems are confronted with operational challenges, including mechanical and power quality issues, leading to increased energy demand consumption and emissions of greenhouse gases [2]. To address these problems and guarantee the energy-efficient transport of vaccines, it is crucial to develop portable thermoelectric cooling units that utilize renewable energy sources. These facilities have the potential to mitigate the climate change by lowering carbon emissions. Thermoelectric coolers, utilizes the Peltier effect, which is a method of heat transfer in solid-state materials involving dissimilar semiconductors, offers several advantages such as the absence of fluid circulation, no moving mechanical parts, and no emission of hazardous gases [3]. Unlike traditional refrigeration mechanism, which depends upon compressors, evaporators, and condensers, the thermoelectric cooling systems uses three main components: a cold junction, a heat sink unit, and a DC power source. Instead of using a standard refrigerant for heat extraction, two dissimilar conductors are used and the heat is absorbed and transferred by the electron movement across semiconductor materials. The interaction between N-type and P-type semiconductors in Peltier modules, each characterized by distinct electron behaviors, is vital to this heat extraction. These Peltier modules operate on the Seebeck effect principle to move the heat from hot to cold regions. It employs materials such as bismuth telluride and the process enable refrigeration without using the conventional refrigerants and mechanical devices, offering an efficient alternative of cooling [4].

The thermoelectric cooling system constructed from two dissimilar semiconductor materials, can provide cooling or heating by leveraging the temperature differential between their junctions when an electric current passes through them. This technology offers several advantages, including lower maintenance requirements, reduced environmental impact due to the absence of refrigerants, and greater energy efficiency in specific cooling applications [5]. Additionally, Peltier-based refrigeration systems can be compact and versatile, making them suitable for a range of scenarios, from portable coolers to medical equipment and electronics cooling, where precision temperature control is crucial. Consequently, thermoelectricity with Peltier modules holds the potential to revolutionize the refrigeration industry by offering a more sustainable and efficient cooling solution.

In recent scientific research, there has been a significant emphasis on the design and development of Peltier-based thermoelectric cooling storage systems. In [6], the focus is on the geometric optimization of thermo-elements within a thermoelectric cooler to enhance cooling capacity and coefficient of performance. This optimization effort emphasizes the identification of optimal module thickness and operating current values, factors that are influenced by considerations such as overall heat dissipation and external thermal resistances. The adjustment of the cross-sectional area of pellets as a method to precisely regulate the operating current and voltage of a thermoelectric module is discussed in [7]. Several studies have proposed and tested different designs and configurations of thermoelectric cooling storage boxes using Peltier modules. The main factors that affect the performance and efficiency of the storage box are the size, shape, material, and arrangement of the Peltier module, the heat sink, the fan, the insulation, and the phase change material [8]. The experimental results show that the thermoelectric cooling storage box can achieve a temperature range of 5 °C to 25 °C, depending on the ambient temperature and the load [9]. Rudresha et al. in 2023 utilized ANSYS Workbench and CFD software to optimize thermoelectric refrigeration systems, emphasizing modifications in insulating materials and internal design, ultimately revealing a substantial 9.4 °C temperature difference for the sharp edge design with nickel insulation and underscoring the profound influence of design changes on system performance [10]. The impact of changing the cross-sectional area of the thermo-elements in the cooling box on both the maximum cooling capacity and the maximum achievable coefficient of performance is discussed in [11]. The study in [12] addresses several critical factors concerning TEC design to employ a genetic search method to optimize the most optimum dimensions for the TEC, ultimately seeking to enhance TEC performance and efficiency. Siddique et al. in 2023 improved solid-state thermoelectric cooling by integrating phase change material (PCM), finding that its incorporation not only increased cooling capacity but also enhanced storage volume, presenting a promising performance for the advancement of thermoelectric refrigeration systems [13].

In [14], a small thermoelectric Peltier cooler (20 x 26 x 18 mm) is designed using a Peltier thermoelectric cell between external and internal heat sinks, allowing efficient heat removal from a refrigeration box. The cooler achieved a coefficient of performance (COP) exceeding 0.5 and it efficiently lowered the temperature within the cooler box from the ambient temperature to 18.5°C while dissipating 25W of heat. A thermoelectric refrigerator, utilizing the Peltier effect, was specifically designed to run on solar energy while effectively maintaining a temperature range between 2°C and 8°C which exhibits an average COP value of 0.004 [15]. In 2021 Afshari conducted a comparative analysis of air-to-air and air-to-water thermoelectric cooling unit utilizing Peltier elements. His findings revealed that the air-to-water mode exhibited a superior COP compared to the air-to-air mode, with a notable increase of 30–50% [16]. In [17], the design of a portable mini thermoelectric cooler is discussed that employs the Peltier Effect for optimizing the operational conditions, particularly fan voltages for the thermoelectric cooler, and conducts performance analysis, including the COP, to determine the most efficient operating conditions. A TEC is utilized in [18] to directly control the temperature within a thermoelectric cooler by circulating cooling water through two aluminum blocks. The research centers on analyzing the impact of the temperature of the heat sink and flow rate via calculations, ultimately achieving a COP of 0.73. The experimental data in [19] demonstrated the effectiveness of a thermoelectric cooling system when used as a cooling box, both with and without products to be cooled and in both scenarios, there was a temperature difference of 4.865°C after a duration of 90 minutes. The study in [20] explores the performance of a portable TEC box using the Peltier effect and air-cooling heat sink, with a capacity of 22 liters. The research investigates the thermal performance of the TEC under varying input power levels (50.5W, 72.72W, and 113.64W) and cooling loads (1440 mL and 2880 mL at 113.64W input power). The results indicate that as input power increases, the box temperature decreases, albeit at the cost of reduced COP, as higher input power absorbs more energy. In terms of cooling load, greater cooling load leads to longer temperature stability in the box, as more energy is required to lower the box's temperature.

This paper discusses the design of a portable solar-powered vaccine carrier box, emphasizing the utilization of the Peltier Effect for effective vaccine cooling. The first step involved assessing the cooling capacity required for this application, considering the availability of TEC modules with varying voltage, current, and heat extraction capabilities. To cool the hot side of the vaccine holder, a heat sink and fan assembly were employed, chosen over water cooling due to size and complexity considerations. An efficient heat exchanger was deemed essential for effectively cooling the TEC module's hot surface. The design also encompassed a solar power supply, featuring photovoltaic panels, a charge controller, and batteries. The design of the cooling holder was developed in SolidWorks, with thermal analysis in Flow Simulation, and MATLAB simulations were used to determine the exact dimensions of the prototype before finalizing the design in SolidWorks. The following sections of the paper is organized as, section 2 focuses on functional architecture and mathematical modeling of vaccine box, and section 3 based on design of vaccine box, section 4 described the results and discussion, while section 5 comments on conclusion of the presented research work.

2. Design of Thermoelectric Module

The design of a portable solar-powered thermoelectric cooler should incorporate essential attributes for an effective cold chain delivery system. The schematic representation of the TEC module is shown in Figure.1.

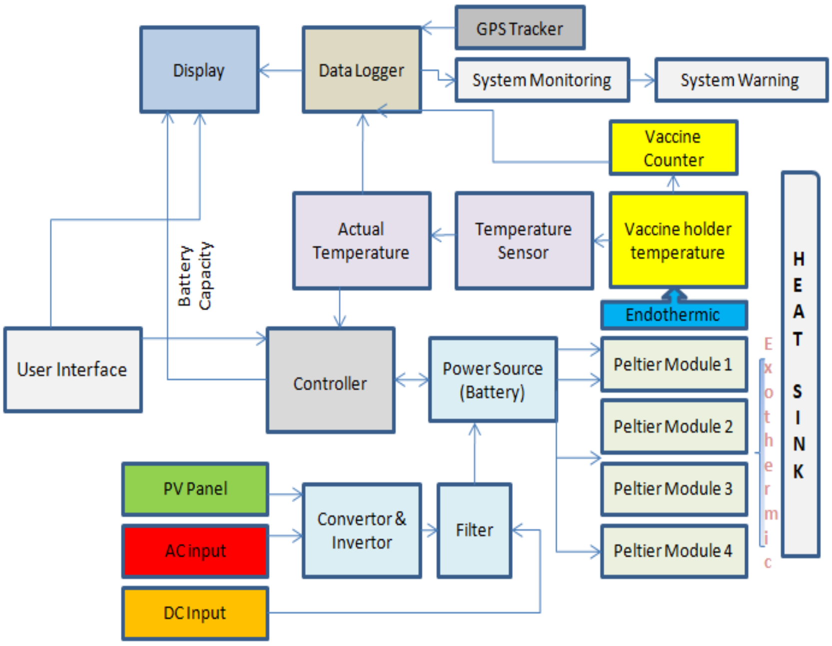

Figure 1. Functional flow diagram of Thermoelectric Cooler Module

The design process involves several key steps, including calculating electrical power, conducting heat transfer calculations, determining the COP, mathematical model and accurately sizing the storage box dimensions. When designing the thermoelectric module, it is crucial to select material with a high seebeck coefficient, electrical conductivity, and low thermal conductivity to achieve a high Figure of Merit (ZT) and power factor. Heat transfer losses often occur due to inadequate insulation distribution, leading to temperature loss. Therefore, optimal design selection requires the choice of materials that exhibit chemical, thermal, and mechanical stability.

2.1. Mathematical Model of Thermoelectric Module

A Peltier Module is a semiconductor device composed of specific P-type and N-type materials, typically made from Bismuth Telluride (Bi2Te3). Its operation involves applying a DC power supply to create a temperature difference between its two sides: one side is kept cooler, while the other remains at a higher temperature. The thermoelectric effect encompasses several phenomena, including the Seebeck effect, Peltier effect, Thomson effect, Fourier's law of heat conduction, and Newton's law of cooling. To optimize the efficiency of the thermoelectric cooling system, dedicated heat exchangers and heat sinks units are connected to the hot side of the chip. These components serve dual function: they dissipate excess heat produced during cooling and enhance overall thermal efficiency. By maintaining a consistent temperature difference between the hot and cold sides, the thermoelectric device becomes suitable for various cooling applications, such as refrigeration and temperature control electronic devices. The cooling capacity (QL) and Input power P of a Peltier thermoelectric cooler is given in (1) and (2) [21].

$$Q_L = \alpha I T_L - \frac{1}{2} I^2 R - K_t (T_H - T_L) \tag{1}$$

$$P = \alpha I (T_H - T_L) + I^2 R \tag{2}$$

$I^2 R$ shows joule heating effect and it is irreversible, α is the seebeck coefficient, K_t is total thermal conductivity, T_H is the temperature of hot end of the module, T_L is the cold end temperature of the module. Equation (2) can be write as,

$$V = \alpha(T_H - T_L) + IR \quad (3)$$

Equation (3) is reffered as voltage balance equation of TEC. Whereas the total heat rejection equation is given by,

$$Q_H = \alpha I T_H + \frac{1}{2} I^2 R - K_t (T_H - T_L) \quad (4)$$

The COP of a thermoelectric module using a peltier module can be defined as the ratio of the Cooling capacity at the cold end to the electrical power input P_{in}. It quantifies the efficiency of the cooling system. The COP can be expressed as in (5).

$$COP = \frac{Q_L}{P_{in}} \quad (5)$$

$$COP = \frac{\alpha I T_L - \frac{1}{2} I^2 R - k_t (T_h - T_c)}{\alpha I (T_h - T_c) + I^2 R} \quad (6)$$

The Figure of Merit (ZT) for a thermoelectric module using a Peltier module is a critical parameter that quantifies its thermoelectric performance. ZT is a dimensionless quantity that reflects the efficiency of a thermoelectric material in converting heat into electrical power (or vice versa). A higher ZT value indicates better thermoelectric performance, as it suggests that the material is a more efficient heat-to-electricity converter. Achieving a high ZT value is a key goal in thermoelectric material research, as it leads to more efficient thermoelectric module. ZT is expressed in (7) as [22].

$$ZT = \frac{\alpha^2 \sigma T}{K_t} \quad (7)$$

Where, α and σ represents the seebeck coefficient and electrical conductivity respectively, T corresponds to absolute temperature, and K_t is the Thermal conductivity.

3. Design of Vaccine Storage Box

The design of the storage box for the proposed thermoelectric cooling system considers a range of factors that ensure its optimal performance and suitability for the specific application. The design specifications for the storage box are detailed in Table 1 and visually presented in Figure 2.

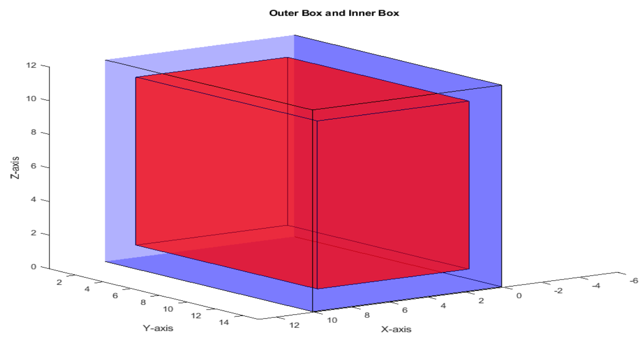

Figure 2. Dimensions of the vaccine storage box

Table 1. Specification of Rectangular Box

Specifications		Dimensions (cm)
Outer box dimensions	Width	10

	Height	15
	Depth	12
	Width	8
Inner box dimensions	Height	13
	Depth	10
	Width	2
Insulation	Height	2
	Depth	2

This project employs four 12V DC 3.5A) peltier modules, known for their vibration-free and noise-free operation, with a maximum power consumption of up to 235W and a Tmax of 70°C. These modules are used to convert electrical energy into cooling thermal energy, effectively maintaining the temperature of the vaccine stored in a polystyrene box.

To optimize cooling capacity, heat-sinks play a crucial role in efficiently dissipating heat from the Peltier modules, preventing overheating. In this system, all the Peltier modules are arranged in parallel and four heat-sinks are strategically positioned outside the cooling box to manage heat effectively.

The inner box serves as the primary storage space for items requiring cooling, reducing the loss of cool air. The power supply, a 24V Adjustable DC power supply with low ripple/noise, is the primary source of electrical energy to operate the system. Four CPU fans are further used to dissipate heat in the light-weight wooden casing, ensuring uniform heat extraction from the polystyrene box into the atmosphere. Thermal paste is employed as an adhesive medium to bond the Peltier modules, heat-sinks, and fans while facilitating heat transfer. Connecting wires establish the electrical circuit, linking the Peltier cooling elements to the power supply and connecting the power supply to the electrical energy source via a plug. Additionally, a 12V 180W solar panel is integrated into the system to provide power during daylight hours. For backup power, eight Rechargeable Li-Po 3.7V 4500mAh batteries are included, ensuring uninterrupted operation of the thermoelectric storage box for 3 hours.

The backup time is calculated using equation i.e.

Backup duration (hours) = Battery Capacity (Ah) × Input voltage (V) / Total Load (Watts) as $Backup\ time = (4.5 \times 8 \times 12)/133 = 3.2\ hours$.

Figure.3 gives insights into the cooling performance of the proposed storage system, highlighting its ability to consistently maintain temperatures below 15°C. Common to all scenarios, the cooling process exhibits a gradual start within the initial 15 minutes.

Figure.3. Final Product of Peltier-Based Thermoelectric Cooling Module

4. Results and Discussion

The experiment comprised three distinct conditions:

a. In the first condition, the cooling box was empty, with no load or contents placed inside.

b. In the second condition, 10 5ml sterile glass vaccine tubes filled with water were positioned inside the box.

c. The third condition involved placing 6 5ml sterile glass vaccine tubes filled with water inside the box. Separate results were obtained for each of these conditions, and the outcomes are visually presented in Figure 4.

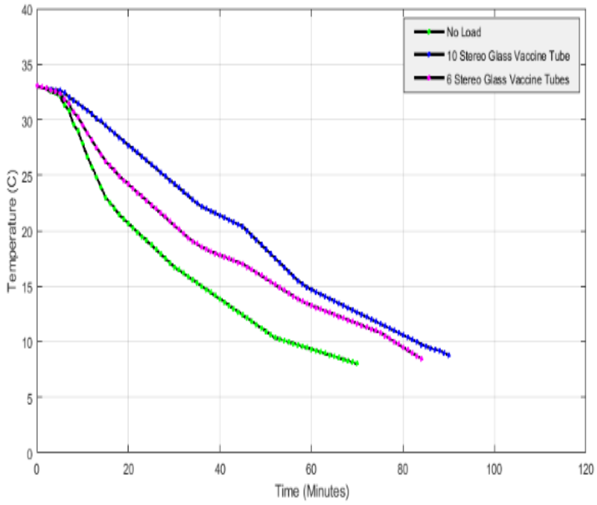

Figure 4. Temperature versus Time taken under all three load conditions

In a no-load condition, where the cooling box contains no vaccine tubes, the temperature experiences a slow initial drop. However, this phase is succeeded by a significant temperature decrease, spanning from 7°C to 18°C. Under these circumstances, it takes 38 minutes to reach 15°C, and the desired temperature of 8°C is attained after 62 minutes. In cases where 5ml sterile glass vaccine tubes filled with water are placed inside the box, the thermoelectric cooler requires approximately 60 minutes to reach 15°C and roughly 90 minutes to achieve the desired temperature of 8°C. The results for the Peltier module with the provided specifications shown in table 2.

Table 2. Specification of TEC Module

Sr.NO	Parameters	Value
1.	number of Peltier modules	4
2.	applied voltage	12V
3.	total current	14A
4.	seebeck coefficient (α):	0.02 V/K
5.	electrical resistance (R)	0.1 ohms
6.	number of Peltier elements (N)	4
7.	thermal conductivity (k)	0.1 W/(m*K)
8.	Hot Side Temperature (T hot)	33°C
9.	Desired Temperature (Tcold):	8°

The results obtained from the performance of peltier module shown in table 2, are as follows as in table 3.

Table 3. Performance of Results

No. of Peltier Modules	4
Electrical Power (W)	168.00
Heat Transfer (W)	70.00
Thermal Resistance (K/W)	0.36
Coefficient of Performance (COP)	0.42

Maximum Achievable Heat Transfer (W)	77.84
Thermal Resistance Limit (K/W)	0.32

These results demonstrate the performance of the Peltier module under the specified conditions, including its electrical power consumption, heat transfer capacity, thermal resistance, and coefficient of performance (COP). The module's COP indicates its efficiency in transferring heat, and in this case, it's 0.42, which is a measure of how well it can achieve cooling. The results show that the Peltier module can transfer 70.00 W of heat while consuming 168.00 W of electrical power. The maximum achievable heat transfer is 77.84 W, which is close to the module's performance limit based on thermal resistance.

5. Conclusion

A portable solar-powered vaccine carrier box that employs the Peltier Effect for efficient vaccine cooling is successfully designed and tested. The analysis of the Peltier module's performance, including its electrical power consumption, heat transfer capacity, thermal resistance, and COP, demonstrates its efficiency in achieving the desired cooling. The system incorporates four 12V DC 3.5A Thermoelectric Cooler (TEC) Peltier Modules, strategically positioned heat-sinks, a 12V 180W Solar Panel for power generation during the day, and eight Rechargeable Li-Po 3.7V 4500mAh batteries for continuous operation for 3 hours. The experimentation involved three different scenarios, revealing the system's cooling capabilities. In an empty cooling chamber, a gradual decline in temperature is observed. Upon introducing 10 sterile glass vaccine tubes filled with water, the temperature decreases more slowly reaching 15°C in 62 minutes and 8°C after 90 minutes. With only 6 vaccine tubes, it takes approximately 55 minutes to reach 15°C and about 90 minutes to attain the desired 8°C temperature. The system exhibits a coefficient of performance (COP) of 0.42, reflecting its efficiency in heat transfer. The results feature the efficacy of the storage system in maintaining the temperatures below 15°C, a critical factor in vaccine preservation.

Funding: The authors extend their acknowledgement to Higher Education Commission (HEC) of Pakistan for funding this work via Project No: 20-16000/NRPU/R&D/HEC/2021 under its National Research Program for Universities (NRPU). Authors also pay their gratitude to the University of Engineering and Technology, Peshawar, Pakistan for their support to carry out this work.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Z. Ng, Y. L. Lean, Q. Y. L. Siang Fei Yeoh, K. S. Lee, A. K. Suleiman, K. B. Liew, Y. W. Kassab and Y. M. A.-W. a. L. C. Ming, "Cold chain time-and temperature-controlled transport of vaccines: a simulated experimental study," Clinical and experimental vaccine research , vol. 9, no. 1, pp. 8-24, 2020.
2. C. Acar, "A comprehensive evaluation of energy storage options for better sustainability," International Journal of Energy Research , vol. 42, no. 12, pp. 3732-3746, 2018.
3. H. J. a. H. J. G. Goldsmid, "The Seebeck and Peltier effects," in The Physics of Thermoelectric Energy Conversion, Morgan & Claypool Publishers, 2017, pp. 2053-2571.
4. M. A. Zoui, S. Bentouba and J. G. S. a. M. Bourouis, "A review on thermoelectric generators: Progress and applications," Energies, vol. 13, no. 14, p. 3606, 2020.
5. C. Jangonda, K. Patil, A. n. Kinikar and R. B. a. M. D. Gavali, "Revi ew of Various Application of Thermoel ectric Module," International journal of innovative research in science, engineering and technology, vol. 5, no. 3, pp. 3393-3400, 2016.
6. K. F. a. S. Ali, "Design of Bulk Thermoelectric Modules for Integrated Circuit Thermal Management," IEEE Transactions on Components and Packaging Technologies, vol. 29, no. 4, pp. 750-757, 2006.
7. M. Hodes, "Optimal Pellet Geometries for Thermoelectric Refrigeration," IEEE Transactions on Components and Packaging Technologies, vol. 30, no. 1, pp. 50-58, 2007.
8. D. a. G. T. Zhao, "A review of thermoelectric cooling: materials, modeling and applications," Applied thermal engineering, vol. 66, no. 1-2, pp. 15-24, 2014.
9. K. G. B. Arjun, B. G. Pruthviraj, K. Y. K. Chethan and P. Rashmi, "Design and implementation of peltier based solar powered portable refrigeration unit," in 2017 2nd IEEE International Conference on Recent Trends in Electronics, Information & Communication Technology (RTEICT), India, 2017.
10. N. Rudresha and V. K. M. a. M. M. Math, "A parametric study and performance investigation of thermoelectric refrigeration system using computational fluid dynamics," nternational Journal of Air-Conditioning and Refrigeration, vol. 30, no. 1, pp. 115, 2023.
11. M. K. Russel and a. C. Y. C. D. Ewing, "A hybrid thermoelectric cooler thermal management system for electronic packaging," in 2010 12th IEEE Intersociety Conference on Thermal and Thermomechanical Phenomena in Electronic Systems, Las Vegas, 2010.
12. V.-H. C. a. W.-K. Lin, "Geometric optimization of thermoelectric coolers in a confined volume using genetic algorithms," Applied Thermal Engineering, vol. 25, no. 17-18, pp. 2983-2997, 2005.
13. A. R. M. Siddique, M. Bozorgi, K. Venkateshwar and S. T. a. S. Mahmud, "Phase change material-enhanced solid-state thermoelectric cooling technology for food refrigeration and storage applications," Journal of Energy Storage, vol. 60, p. 106569, 2023.
14. M. F. Remeli, N. E. Bakaruddin, S. Shawal, H. Husin and M. F. O. a. B. Singh, "Experimental study of a mini cooler by using Peltier thermoelectric cell," IOP Conference Series: Materials Science and Engineering, vol. 788, no. 1, p. 012076, 2020.
15. J. A. D. Nohay, J. K. H. D. Belen, J. V. B. Claros, R. B. P. Lupo, A. B. Barrato, J. C. D. Cruz, T. M. Amado and M. C. E. Manuel, "Design and Fabrication of a Portable Solar Powered Thermoelectric Refrigerator for Insulin Storage," in 2020 11th IEEE Control and System Graduate Research Colloquium (ICSGRC), Shah Alam, Malaysia, 2020.
16. F. Afshari, "Experimental and numerical investigation on thermoelectric coolers for comparing air-to-water to air-to-air refrigerators," Journal of Thermal Analysis and Calorimetry, vol. 144, p. 855–868, 2021.
17. A. Çağlar, "Optimization of operational conditions for a thermoelectric refrigerator and its performance analysis at optimum conditions," International Journal of Refrigeration, vol. 96, pp. 70-77, 2018.
18. A. Kherkhar, Y. Chiba, A. Tlemçani and H. Mamur, "Thermal investigation of a thermoelectric cooler based on Arduino and PID control approach," Case Studies in Thermal Engineering, vol. 36, p. 102249, 2022.
19. R. Ab Rahman, M. A. H. Mohamad, M. Kaamin, M. F. M. Batcha, M. D. A. Mazlan and M. L. R. a. M. A. A. C. Aziz, "Experimental study of Peltier-Based Thermoelectric Cooling Box System," Journal of Advanced Research in Applied Mechanics, vol. 94, no. 1, pp. 1-6, 2022.
20. K. Mainil and A. A. a. M. Akmal, "Portable thermoelectric cooler box performance with variation of input power and cooling load," Aceh International Journal of Science and Technology, vol. 7, no. 2, pp. 85-92, 2018.
21. Ferrotec, [Online]. Available: https://thermal.ferrotec.com/technology/thermoelectric-reference-guide/thermalref11/.
22. A. C. Sulaiman, N. A. M. Amin, M. H. Basha, M. S. A. Majid and N. F. b. M. N. a. I. Zaman, "Cooling performance of thermoelectric cooling (TEC) and applications: a review," in MATEC Web of Conferences, 2018.