

Experimental Analysis of Temperature-Control Food Delivery Box Using Peltier Module

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Abstract - This study presents an experimental evaluation of refrigeration and heating employing a Peltier module based on the thermoelectric effect. The objective is to assess the performance, efficiency, and temperature variation characteristics of the Peltier device for both cooling and heating applications. A prototype system was designed and constructed using a thermoelectric module, heat sinks, a cooling fan, and a power-supply configuration. Experiments were performed under varying operating conditions to track temperature changes on the module's hot and cold faces over a defined time interval. Results indicate that the Peltier module can achieve effective cooling and heating in a compact, low-maintenance, and environmentally friendly manner. The cooling side exhibited a pronounced temperature decrease, while the heating side experienced a substantial temperature rise during operation. The findings suggest that thermoelectric refrigeration systems may offer a viable alternative to conventional refrigeration methods for small-scale and portable applications, owing to their simplicity, noiseless operation, and absence of harmful refrigerants.

Key Words: Peltier Module, Thermoelectric Refrigeration, Thermoelectric Effect, Temperature-Controlled Food Delivery.

1.INTRODUCTION

The increasing popularity of app-based food delivery services has created a demand for systems capable of preserving food temperature during transportation. Maintaining the desired temperature of food products remains a significant challenge, particularly when deliveries involve extended travel times or varying environmental conditions. Exposure to surrounding temperatures can cause hot meals to cool down and chilled items to lose their freshness, ultimately affecting taste, texture, quality, and consumer experience. Traditional delivery containers primarily rely on insulating materials, which can only slow temperature changes and are often insufficient for long-duration deliveries.

Thermoelectric technology offers a practical approach for temperature regulation in portable applications. This technology operates on the thermoelectric principle, where electrical energy is used to create a temperature difference across a semiconductor device. When electric current passes through the module, heat is transferred from one surface to the other, producing a cooling effect on one side and a heating effect on the opposite side. Due to their compact size, silent operation, absence of mechanical compressors, and

environmentally friendly characteristics, thermoelectric modules are well suited for mobile temperature-control systems.

The present work focuses on the development and performance evaluation of a thermoelectric food delivery box designed to maintain food at appropriate temperatures during transportation. The objective is to investigate the capability of the system to provide both cooling and heating functions and to determine its suitability for practical delivery operations. The study examines the thermal performance of the developed prototype under various operating conditions to assess its effectiveness in preserving food quality.

The proposed system incorporates a thermoelectric module, aluminum heat sinks, cooling fans, temperature-sensing devices, an insulated storage compartment, and a power supply arrangement. The insulated chamber helps reduce unwanted heat exchange with the external environment, while the heat sinks and fans facilitate efficient removal of heat from the module. The combined operation of these components enables the system to maintain a controlled temperature inside the storage compartment for an extended period.

Experimental investigations are carried out to evaluate the thermal behavior and operational performance of the prototype. Key parameters including chamber temperature, cooling and heating response, temperature stability, and electrical energy consumption are monitored and recorded. In cooling mode, the system is tested for its ability to reduce and sustain temperatures suitable for beverages and temperature-sensitive food items. In heating mode, its performance is examined for maintaining the warmth of freshly prepared meals. Temperature measurements are collected at regular intervals to analyze system behavior under realistic delivery conditions.

The obtained results provide an understanding of the factors affecting thermoelectric performance in food transportation applications. The effectiveness of the system is found to depend on operating voltage, ambient conditions, insulation effectiveness, and heat dissipation efficiency. Enhanced removal of heat from the hot side of the thermoelectric module contributes significantly to improved thermal performance. Furthermore, the energy efficiency of the prototype is assessed using performance indicators such as the coefficient of performance (COP), allowing comparison of system behavior under different operating situations and loading conditions.

The study confirms that thermoelectric technology can be successfully applied in portable food delivery systems requiring both heating and cooling capabilities. The developed prototype demonstrates reliable temperature control while maintaining a compact and lightweight configuration. Although thermoelectric devices generally operate at lower efficiency levels than conventional refrigeration systems, their advantages—including low maintenance requirements, noise-free operation, simple control mechanisms, and dual-function capability—make them attractive for small-scale temperature-control applications. The findings of this research may support future advancements in smart food delivery solutions aimed at improving food preservation, customer satisfaction, and sustainable transportation practices.

2. PROBLEM STATEMENT

The growing dependence on food delivery platforms has highlighted the importance of maintaining appropriate food temperatures throughout the delivery process. During transportation, food is exposed to changing environmental conditions that can alter its temperature before it reaches the customer. Warm meals may cool down over time, while refrigerated or cold products may become warmer, reducing their quality and appeal. These temperature variations can affect flavor, texture, freshness, and, in some cases, food safety, ultimately influencing the overall customer experience.

Traditional delivery bags and containers are generally designed with insulating materials that help delay heat transfer between the food and the external environment. Although such insulation can provide temporary temperature retention, it does not actively regulate temperature and becomes less effective during longer delivery periods. As a result, maintaining consistent food temperatures remains a challenge, particularly when deliveries are made over greater distances or under unfavorable weather conditions.

To overcome these limitations, an active temperature-control approach is required. The present work focuses on the design and development of a food delivery box equipped with a thermoelectric module operating on the Peltier principle. By utilizing thermoelectric technology, the system is capable of producing both cooling and heating effects within a single unit. This enables the storage chamber to maintain suitable temperatures for different categories of food products during transportation.

The proposed temperature-controlled box is intended to preserve food quality throughout the delivery cycle while remaining compact, portable, and energy efficient. In addition to enhancing the condition of delivered food, the system offers a practical and environmentally conscious solution for modern food transportation applications. The implementation of such technology has the potential to improve customer satisfaction and support the growing demand for reliable temperature-controlled delivery systems.

3. OBJECTIVES

This project aims to design, construct, and assess a temperature-regulated food delivery box incorporating a thermoelectric (Peltier) module for thermal control during

transportation. The system is intended to maintain appropriate temperatures for different food items by providing both heating and cooling functions within a single unit. By preserving the desired temperature throughout the delivery process, the box helps retain food quality, freshness, flavor, and overall consumer satisfaction. To improve thermal retention, an insulated storage compartment is integrated into the design, reducing unwanted heat transfer between the interior of the box and the external environment. The project also emphasizes the development of a lightweight, compact, and portable solution suitable for practical food delivery operations.

The study further investigates the operational performance of the developed prototype under different environmental and working conditions. Temperature-sensing devices are employed to monitor variations within the storage chamber and evaluate the system's ability to maintain stable temperatures in both cooling and heating modes. Various factors, including insulation effectiveness, surrounding temperature, and heat removal efficiency, are analyzed to determine their influence on thermal performance. Electrical energy consumption and temperature-retention characteristics are also examined to assess the overall efficiency and feasibility of the system. In addition, the performance of the thermoelectric food delivery box is reviewed against conventional delivery containers to identify its advantages, limitations, and suitability for real-world applications.

4. METHODOLOGY

The methodology adopted in this study involves a systematic process for the design, development, and performance evaluation of a temperature-controlled food delivery box utilizing thermoelectric technology. Initially, the problem of temperature loss and gain during food transportation is examined to understand the challenges associated with maintaining food quality during delivery. Various temperature-control approaches are reviewed, and a thermoelectric solution is selected because of its compact structure, ability to provide both heating and cooling functions, low maintenance requirements, and environmentally friendly operation. Based on the identified requirements, key design considerations such as thermal insulation, operating temperature range, power requirements, portability, and heat dissipation are determined. An insulated food delivery container is then prepared and modified to accommodate the thermoelectric module and supporting components. The cooling side of the module is placed inside the storage chamber, while the heating side is connected to heat sinks and cooling fans to facilitate efficient heat removal. Suitable insulating materials are incorporated into the construction to minimize heat exchange with the external environment and enhance thermal retention.

Following the assembly of all components, experimental investigations are carried out to assess the performance of the developed system. The thermoelectric unit is operated under both cooling and heating conditions, and temperature variations within the chamber are continuously monitored using temperature sensors. Experiments are performed under different ambient conditions to study the influence of external temperature on system behavior. Important performance indicators, including temperature

reduction rate, temperature rise rate, thermal stability, and electrical power consumption, are measured and recorded throughout the testing process. The experimental data is subsequently compiled and analyzed to determine the system's capability to maintain the required temperature for food transportation applications. The findings are used to evaluate the practicality and effectiveness of the proposed design. Based on the observed results, recommendations are provided for future improvements, including the use of advanced insulation materials, improved heat dissipation arrangements, and optimized power utilization strategies to enhance overall system performance and reliability.

5. ANALYTICAL CALCULATION

5.1 Data and Assumptions:

The Inside Temperature (T_i) = 25°C

Outside Temperature (T_o) = 30°C

Temperature Difference (DT) = 5°C

Thermal Conductivity (k) = 0.03 W/m·K

Surface Area (A) = 0.5 m²

Insulation Thickness (L) = 0.01 m

Peltier Module:

Voltage (V) = 12 V

Current (I) = 4 A

Object:

Mass (m) = 0.5 kg

Specific Heat Capacity (C_p) = 4200 J/kg·K

5.2 Heat Load Due to Conduction

$$\text{Formula: } Q_{\text{cond}} = \frac{(k \times A \times DT)}{L}$$

$$Q_{\text{cond}} = 7.5 \text{ W}$$

5.3 Heat Load Due to Air Infiltration

Assumed Air Infiltration Load: $Q_{\text{air}} = 2 \text{ W}$

5.4 CASE A: Cooling Water Bottle (28°C to 20°C)

a) Heat Removed from Water:

$$Q_{\text{water}} = m \times C_p \times \Delta T$$

$$Q_{\text{water}} = 0.5 \times 4200 \times (28 - 20)$$

$$Q_{\text{water}} = 16800 \text{ J}$$

$$Q_{\text{water}} = 16.8 \text{ kJ}$$

b) Equivalent Water-Cooling Load:

$$Q_{\text{water, cooling}} = \frac{Q_{\text{water}}}{t}$$

$$Q_{\text{water, cooling}} = 16800/3600$$

$$Q_{\text{water, cooling}} = 4.66 \text{ W}$$

c) Total Cooling Load:

$$Q_{\text{total, cooling}} = Q_{\text{cond}} + Q_{\text{air}} + Q_{\text{water, cooling}}$$

$$Q_{\text{total}} = 7.5 + 2 + 4.66$$

$$Q_{\text{total}} = 14.16 \text{ W}$$

d) Input Power to Peltier Module:

$$P = V \times I$$

$$P = 12 \times 4$$

$$P = 48 \text{ W}$$

e) Coefficient of Performance (Cooling):

$$\text{COP}_{\text{cooling}} = \frac{Q_{\text{total, cooling}}}{P}$$

$$\text{COP}_{\text{cooling}} = 14.16 / 48$$

$$\text{COP}_{\text{cooling}} = 0.3$$

f) Cooling Time:

$$t = Q_{\text{water}} / Q_{\text{total, cooling}}$$

$$t = 1186.44 \text{ s}$$

$$t = 19.8 \text{ minutes}$$

5.5 CASE B: Heating Water Bottle (28°C to 45°C)

a) Heat Required for Heating:

$$Q_{\text{water}} = m \times C_p \times \Delta T$$

$$Q_{\text{water}} = 0.5 \times 4200 \times (45 - 28)$$

$$Q_{\text{water}} = 35700 \text{ J}$$

$$Q_{\text{water}} = 35.7 \text{ KJ}$$

b) Equivalent Water Heating Load:

$$Q_{\text{water, heating}} = \frac{Q_{\text{water}}}{t}$$

$$Q_{\text{water, heating}} = 35700/3600$$

$$Q_{\text{water, heating}} = 9.22 \text{ W}$$

c) Total Heating Load:

$$Q_{\text{total, heating}} = Q_{\text{cond}} + Q_{\text{air}} + Q_{\text{water, heating}}$$

$$Q_{\text{total}} = 7.5 + 2 + 9.22$$

$$Q_{\text{total}} = 19.42 \text{ W}$$

d) Input Power to Peltier Module:

$$P = V \times I$$

$$P = 12 \times 4$$

$$P = 48 \text{ W}$$

e) Coefficient of Performance (Heating):

$$\text{COP}_{\text{heating}} = \frac{Q_{\text{total, heating}}}{P}$$

$$\text{COP}_{\text{heating}} = 19.42 / 48$$

$$\text{COP}_{\text{heating}} = 0.405$$

f) Heating Time:

$$t = Q_{\text{water}} / Q_{\text{total, heating}}$$

$$t = 1838 \text{ s}$$

$$t = 30.6 \text{ minutes}$$

5.6 Summary Results**a) Cooling case (28°C to 20°C)**

Conduction Load = 7.5 W

Air Infiltration Load = 2 W

Water Cooling Load = 4.66 W

Total Cooling Load = 14.16 W

Input Power = 48 W

COP = 0.3

Cooling Time = 19.8 min

b) Heating case (28°C to 20°C)

Conduction Load = 7.5 W

Air Infiltration Load = 2 W

Water heating Load = 9.92 W

Total heating Load = 19.42 W

Input Power = 48 W

COP = 0.405

Heating Time = 30.6 min

systems operate quietly, require minimal maintenance, and are well suited for compact and portable applications.

An important characteristic of the thermoelectric module is its reversible operation. By changing the direction of the supplied current, the flow of heat can be reversed, causing the previously cooled surface to become heated and vice versa. This feature enables a single module to perform both cooling and heating functions, making it an efficient solution for maintaining the desired temperature of various food products during transportation.

In the developed temperature-controlled food delivery system, the cooling surface of the thermoelectric module is installed within the insulated storage compartment. This surface absorbs thermal energy from the enclosed space, thereby reducing the internal temperature and helping to maintain suitable conditions for chilled food products and beverages. Simultaneously, the opposite surface of the module transfers the absorbed heat to the external environment.

To improve thermal performance, the external side of the module is equipped with heat sinks and cooling fans that facilitate continuous heat dissipation. Efficient removal of heat from this side is critical for maintaining the effectiveness of the thermoelectric process, as any accumulation of heat can reduce the temperature difference across the module and lower its overall performance. The insulated chamber further enhances system efficiency by minimizing unwanted heat transfer between the interior and surrounding atmosphere.

The integration of thermoelectric temperature control, effective heat rejection mechanisms, and high-quality insulation enables the delivery box to maintain a more consistent internal temperature during transportation. As a result, the system helps preserve the freshness, quality, and desired serving condition of food products throughout the delivery period.

6. SYSTEM DESIGN

The working mechanism of the temperature-controlled food delivery box is based on thermoelectric heat transfer, commonly referred to as the Peltier effect. A thermoelectric module is constructed using several pairs of p-type and n-type semiconductor elements arranged in a specific configuration. When electrical current passes through these semiconductor junctions, thermal energy is transported from one side of the module to the other, creating a temperature difference across its surfaces.

As heat is extracted from one side, that surface becomes cooler and can be used to reduce the temperature inside the storage chamber. Simultaneously, the opposite side releases the transferred heat and becomes warmer. This heat-pumping phenomenon allows the module to provide temperature control without relying on conventional refrigeration components such as compressors, refrigerants, or mechanically moving parts. Consequently, thermoelectric

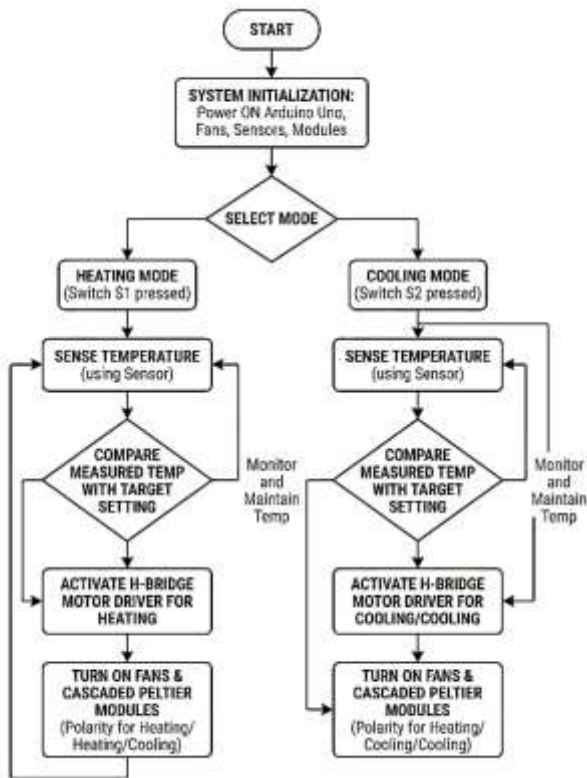


Figure 1: System Flowchart



Figure 3: Prototype Setup

7. EXPERIMENTAL VALIDATION

7.1 Experimental Setup

The experimental setup consists of:

- Insulated food delivery box
- Thermoelectric (Peltier) module (12V, 4A)
- Heat sink with cooling fan (hot side)
- Internal fan for air circulation
- Temperature sensors
- DC power supply
- Test load (water bottle / hot food)

7.2 Experimental Procedure:

Cooling Test:

- Place a 0.5 -liter water bottle at $\sim 29^{\circ}\text{C}$ inside the box.
- Switch ON the Peltier module.
- Record inside temperature at regular intervals (every 10 min).
- Continue until temperature reaches $\sim 20^{\circ}\text{C}$

Heating Test:

- Place hot food ($\sim 30^{\circ}\text{C}$ initially for controlled test or reheat case).
- Reverse polarity of Peltier module (heating mode)
- Record temperature rise inside the box.
- Continue until temperature reaches $\sim 45^{\circ}\text{C}$.



Figure 2: Internal Setup

7.3 Observation and Results:

Case 1 – cooling

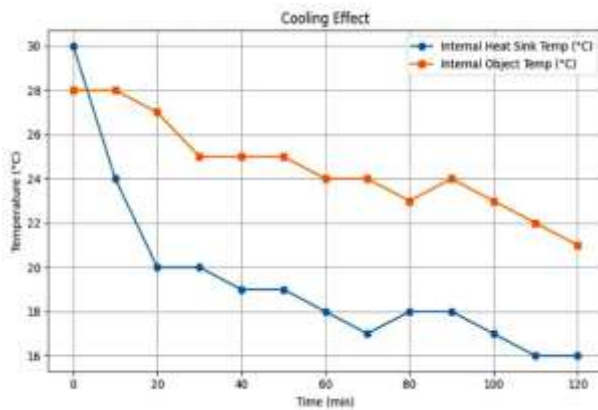


Figure 4: Cooling (Line Graph)

Overall, the results demonstrate that the thermoelectric cooling system effectively reduced the internal temperature of the food delivery box. The heat sink temperature decreased by approximately 14°C (from 30°C to 16°C), while the object temperature decreased by approximately 7°C (from 28°C to 21°C) over the 120-minute test period. The temperature difference between the heat sink and the object remained evident throughout the experiment. These findings validate the capability of the thermoelectric food delivery box to maintain lower temperatures for food preservation and transportation without the use of conventional refrigeration methods. The temperature difference between the heat sink and the object remained evident throughout the experiment. This difference indicates that the heat sink cooled more rapidly than the object, which is typical in thermoelectric cooling systems due to thermal resistance between the cooling source and the load.

Case 2 – Heating

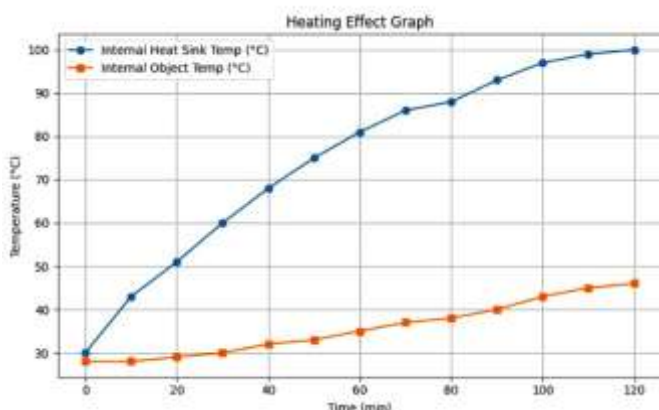


Figure 5: Heating (Line Graph)

The Heating Effect Graph illustrates the temperature variation of the internal heat sink and the internal object during the heating process over a period of 120 minutes. At the start of the experiment, the heat sink temperature is approximately 30°C, while the object temperature is around 28°C. As time progresses, the heat sink temperature increases rapidly,

reaching 60°C within 30 minutes and gradually rising to 100°C at the end of the experiment. In contrast, the object temperature increases at a slower rate, rising from 28°C to 46°C over the same period. This slower increase is due to the time required for heat transfer from the heat sink to the object through the enclosed space. The continuous upward trend of both curves indicates effective heat generation and transfer within the system. The absence of sudden fluctuations demonstrates stable heating performance, while the gradual reduction in the rate of temperature rise towards the end suggests that the system is approaching thermal equilibrium. Overall, the graph confirms that the thermoelectric heating system successfully provides sustained and efficient heating, resulting in a steady increase in the object's temperature over time.

7.4 Comparison between theoretical and experimental values:

Parameter	Theoretical	Experimental
COP (cooling)	0.31	0.25
COP (Heating)	0.405	0.301

The lower experimental COP values suggest that the real system experiences losses that are not fully accounted for in the theoretical analysis. These losses may arise from factors such as heat leakage, friction, imperfect insulation, pressure drops, non-ideal operating conditions, measurement errors, and inefficiencies in system components.

Overall, the results show that the system performs less efficiently in practice than predicted by theory, although the experimental values follow the same trend as the theoretical values, with the heating COP remaining higher than the cooling COP.

Charts

8. CONCLUSIONS

The project entitled “Experimental Analysis of Temperature-Controlled Food Delivery Box Using Thermoelectric (Peltier) Module” was successfully completed with the design, fabrication, and testing of a functional prototype. The study was undertaken to address the common problem of temperature loss during food transportation, which often affects the quality, freshness, and customer satisfaction associated with delivered food items. By incorporating a thermoelectric module into an insulated delivery box, the system was able to provide both cooling and heating functions within a single compact unit. The experimental results demonstrated that the proposed design could effectively maintain the internal temperature of the box for a reasonable period, making it suitable for short-distance and medium-duration food delivery applications.

The performance analysis showed that the Peltier module was capable of producing a significant temperature difference between its hot and cold surfaces when supplied with direct current. During cooling operation, the temperature inside the chamber gradually decreased and stabilized after a certain duration, while in heating mode the temperature increased steadily and remained within the desired range. The effectiveness of the system was strongly influenced by factors such as insulation quality, ambient conditions, heat sink design, airflow provided by cooling fans, and electrical input power. Proper heat dissipation from the hot side was found to be essential for achieving better cooling performance. The experiments also highlighted the importance of thermal insulation in reducing unwanted heat transfer and improving temperature retention inside the chamber. Overall, the obtained results confirmed that thermoelectric technology can successfully be applied for maintaining food temperature during transportation.

One of the most significant advantages observed during the project was the simplicity and portability of the developed system. Unlike conventional refrigeration systems that require compressors, refrigerants, and complex mechanical arrangements, the thermoelectric setup operates silently with very few components. The absence of harmful refrigerants makes the system environmentally friendly and safer for everyday use. In addition, the compact size, lightweight construction, and low maintenance requirements make it highly suitable for modern food delivery services, especially in urban areas where quick transportation and convenience are important. Although the efficiency of thermoelectric modules is lower than that of traditional refrigeration systems and continuous power supply is required for operation, these limitations are outweighed by the benefits offered in small-scale applications. Therefore, it can be concluded that the proposed temperature-controlled food delivery box provides a practical, innovative, and sustainable solution for preserving food quality during transit. Future improvements such as enhanced insulation, intelligent temperature control systems, battery backup integration, and advanced heat dissipation techniques can further improve the performance and commercial viability of the system.

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REFERENCES

1. M. Seyednezhad, et al., "Solar-powered thermoelectric cooling and heating system," *Energies*, vol. 14, no. 17, pp. 5573, 2021
2. D. Astrain, J. G. Vián, and M. Domínguez, "Increase of COP in the thermoelectric refrigeration by the optimization of heat dissipation," *Applied Thermal Engineering*, vol. 30, no. 6–7, pp. 604–610, 2010.
3. V. Venkata Ramana, et al., "Design and development of thermoelectric cooler," *International Journal of Engineering Research & Technology*, vol. 3, no. 10, pp. –, 2014.
4. A. R. Mazhar, et al., "Experimental investigation of simultaneous cooling and heating using thermoelectric module," *International Journal of Thermofluids*, vol. __, no. __, pp. –, 2023.
5. Elvin Chris Dsouza, "Review of Peltier refrigeration: Advancements and applications," *International Journal of Scientific Research in Engineering and Management*, vol. __, no. __, pp. –, 2024.
6. Riffat S. B. and Ma Xiaoli, "Thermoelectric refrigeration: An overview," *Applied Thermal Engineering*, vol. 23, no. 8, pp. 913–935, 2003.
7. M. K. Shilpa, et al., "A systematic review of thermoelectric Peltier devices: Applications and limitations," *Fluid Dynamics & Materials Processing*, vol. __, no. __, pp. –, 2022.
8. S. Lineykin et al. (2007). Modeling and analysis of thermoelectric modules using SPICE-compatible equivalent circuits.