Thermofusion: Dual Heating and Cooling System Using Peltier Module

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Abstract

This paper presents the design and development of a two-in-one refrigerator and heating system utilizing Peltier modules, which are semiconductor devices capable of both heating and cooling through the Peltier effect. In this system, the refrigerator and heating share a common Peltier module setup, with one side of the module providing cooling for refrigeration, while the opposite side generates heat for the heating. A controlled mechanism is introduced to isolate the two compartments and maintain appropriate temperatures for each function. Temperature regulation is achieved through sensors and microcontroller-based control circuits, which dynamically adjust the electric current to optimize performance for both heating and cooling processes. COP Cooling capacity and Cooling power is analyzed for different input parameters

Keywords: Thermoelectric effect, Peltier Effect, Solid-state Cooling, Refrigeration, Heating, Coefficient of performance.

1. Introduction

In recent years, the demand for compact, energy-efficient appliances has grown significantly due to increasing urbanization and limited living spaces. Conventional kitchen appliances, such as refrigerators and heatings, often require substantial space and energy to operate. This has led to the exploration of alternative technologies, such as Peltier modules, which offer the potential for smaller, more flexible designs. Peltier modules, based on the thermoelectric effect, are semiconductor devices capable of both cooling and heating by transferring heat when an electric current is applied. Traditional refrigeration and heating systems use different technologies that are typically energy-intensive and require separate appliances. Refrigerators generally rely on vapor compression systems that use refrigerants, which can have negative environmental impacts, while heatings use resistive heating elements. The Peltier effect provides an innovative approach by utilizing thermoelectric cooling and heating within a single system. The ability of Peltier devices to create both hot and cold surfaces open up new possibilities for multi-functional appliances. Titov et al. (1997) [1] Presents a new perspective on the Peltier effect in thermoelectric. Y. A. Çengel et al. [2] Çengel and Boles' *Thermodynamics: An Engineering Approach* provides a comprehensive introduction to thermodynamic principles, focusing on real-world engineering applications. It covers key topics like energy conservation, entropy, and power cycles with a strong emphasis on problem-solving and practical examples. Suwit Jugsujinda et al. [3] The authors analyze the performance of a thermoelectric refrigerator (TER) using a thermoelectric cooler (TEC). They evaluate its cooling efficiency, temperature variation, and coefficient of performance (COP). Their results show that the TER can achieve a maximum COP of 0.65, making it a viable alternative for low-maintenance refrigeration, especially in developing regions. H. D. Young et al. [4] Young and Freedman’s *University Physics* provides a comprehensive introduction to classical physics, covering mechanics, thermodynamics, electromagnetism, optics, and modern physics. It emphasizes problem-solving, mathematical rigor, and conceptual understanding, making it a fundamental resource for physics students. D. Halliday et al. [5] Halliday, Resnick, and Walker’s *Fundamentals of Physics* is a widely used textbook that covers core physics topics, including mechanics, thermodynamics, electromagnetism, optics, and modern physics. It emphasizes conceptual understanding, problem-solving skills, and real-world applications, making it a fundamental resource for physics students.thermodynamics, electromagnetism, optics, and modern physics. It emphasizes problem-solving, mathematical rigor, and conceptual understanding, making it a fundamental resource for physics students.Gurevich et al. [6] The paper discusses the lowest achievable temperature in thermoelectric cooling systems, presented at the 4th International Conference on Electrical and Electronics Engineering in 2007. Rudresh N et al. [7]. The paper presents a parametric study and performance analysis of thermoelectric refrigerators. H. Xu, K.M. Kleinke et al. [8] The paper investigates the thermoelectric performance of Niymo3Sb7-xTex (y≤0.1, 1.5≤x≤1.7) in the context of applied physics. Dong Haihong et al. [9]. The paper examines the pressure drop in two-phase flow within an inner evaporative cooling generator at the Asia-Pacific Power and Energy Engineering Conference 2012. N. Maekawa et al. [10] The paper discusses the development of Peltier modules for commercial use, presented at the XVII International Conference on Thermoelectric in 1998. Caglar A. et al. [11]. The paper optimizes the operational conditions of a thermoelectric refrigerator and analyzes its performance under these optimal conditions. Chang.C. C et al [12]. The paper presents a thermoelectric air-cooling module designed for cooling electronic devices Cheng Y H et al. [13] The paper uses a genetic algorithm to maximize the cooling capacity and coefficient of performance (COP) of two-stage thermoelectric coolers. Dimri N et al. [14] The paper presents a thermal model of a semi-transparent photovoltaic thermal (PVT) system integrated with a thermoelectric cooler (TEC) collector.

The challenge lies in developing a dual-function system that combines both refrigeration and heating capabilities within a single appliance. Conventional methods require significant space and energy to maintain separate systems for heating and cooling. There is a need for a compact, environmentally friendly, and energy-efficient solution that addresses both functions without compromising performance. Additionally, efficient thermal management and control mechanisms are required to ensure that the system can maintain appropriate temperatures for both refrigeration and heating operations.

This project aims to design and implement a two-in-one heating and refrigerator using Peltier modules. The system will offer a compact solution for small living spaces, such as dormitories, RVs, and studio apartments. The project will focus on optimizing the thermoelectric cooling and heating process, ensuring energy efficiency, and developing a user-friendly interface for switching between modes. Furthermore, the design will incorporate smart controls to regulate temperatures and manage energy consumption. By utilizing Peltier technology, this appliance seeks to offer a versatile, eco-friendly alternative to traditional refrigeration and heating systems.

The objective of this study is to analyze the potential of thermoelectric refrigeration and heating systems as an alternative to conventional methods, focusing on their energy efficiency, environmental impact, and practical applications. Specifically, the study aims to:

1. Investigate the Peltier effect as the underlying principle of thermoelectric refrigeration and heating.
2. Evaluate the performance and efficiency of thermoelectric modules in comparison to traditional systems.
3. Identify key thermoelectric materials and their influence on system performance.
4. Explore the potential for waste heat recovery and its integration into renewable energy systems.
5. Propose design improvements and material innovations to enhance the overall coefficient of performance (COP) of thermoelectric devices.
6. Assess the feasibility of widespread adoption in various industries, particularly in applications requiring precise temperature control and sustainability.

2. Analysis

To conduct an analysis of a two-in-one heating and cooling system using a Peltier thermoelectric module, we'll assume specific characteristics for a typical commercial thermoelectric module (such as a TEC1-12706) and analyze its behavior under different operating conditions. The TEC1-12706 is a commonly used thermoelectric module that offers reasonable performance for cooling and heating applications.

Parameters to Analyze:

1. Heat Pumping Capacity (Qc and Qh)

Qc (cooling) = how much heat the module can absorb.
Qh (heating) = how much heat the module can dissipate.

2. COP (Cooling and Heating)

Ratio of useful heat (absorbed or dissipated) to the input electrical power.

3. Power Consumption

How much power is consumed under different temperature gradients?

4. Efficiency vs. Voltage
How efficiency varies with the input voltage.

5. Temperature Difference (ΔT) vs. Current and Voltage
How ΔT changes with the applied current or voltage

Analytical equations

1. Heat Absorbed (Qc):

$$Q_c = \alpha \cdot I \cdot T_c - \frac{1}{2} I^2 \cdot R - K \cdot (T_h - T_c) \quad \ldots\ldots\ldots\ldots\ldots \text{Eq (1)}$$

The heat absorbed at the cold junction Qc of a thermoelectric module is given by Eq (1). this equation is derived from the energy balance at the junctions discussed by Titov, O. Yu, Gonzalez de la, G. Cruz, G.N. Logvinov and Gurevich Yu.G in [1]

Where ∝ is the See beck coefficient (V\K)
Where I is the current, (K)
Where T_c is the cold side temperature, (K or C◦)
Where R is the electrical resistance of the module, (Ω)
Where K is the thermal conductance. (W\K)

2.Heat Dissipated (Qh)

(Qh): $Q_h = Q_c + I \cdot V$ ……………………………………… Eq (2)

The heat dissipated at the cold junction Qh of a thermoelectric module is given by Eq (2). this equation is derived from the energy balance at the junctions discussed by Titov, O. Yu, Gonzalez de la, G. Cruz, G.N. Logvinov and Gurevich Yu.G in [1]

Where Qc is the Heat Absorbed, (W)
Where I is the Current, (A)
Where V is the Voltage. (V)

3.Time to reach desired temperature: (t)

t= $\frac{m \times c \times \Delta T}{Q}$ ………………………………… Eq (3)

Represents the estimated Time to cool or heat compartment, As we can use formula for the rate of heat transfer in equation (3). As discussed by Y. A. Çengel and M. A. Boles, "Thermodynamics: An Engineering Approach," 9th ed., McGraw Hill,2019. In [2]

Where t = time to reach desired temp
Where m = mass of air inside the compartment
Where C = specific heat capacity of air (c =1005 J/kg*c)
Where ∆T = desired temp change
Where Q = heat transfer rate

4.Coefficient of Performance (COP):

For Cooling $COP_c = \frac{Qc}{Qh - Qc}$ …………… Eq (4)

represents the coefficient of performance for cooling in equation (4). As discussed by Suwit Jugsujinda*, Athorn Vora-ud, and Tosawat Seetawan in [3]

Where Qc is the Heat Absorbed (W)
Where Qh is the Heat Dissipated (W)
Where P is the power required (I\V)

5. Energy Consumption:

E = P × t …………… Eq (5)

The energy consumed by the system is represented by equation (5). As discussed by H. D. Young and R. A. Freedman, "University Physics," 14th ed., Pearson, 2015. In [4]

Where, E = energy consumption
Where P = power input
Where t = time of operation

6. Power Consumption (P)

$P = V \cdot I$ ……………………………….. Eq (6)

The power consumption by the system represents by equation (6). As discussed by D. Halliday, R. Resnick, and J. Walker, "Fundamentals of Physics," 10th ed., Wiley, 2013. In [5]

Where I is the Current, (A)
Where V is the Voltage. (V)

3. Methodology

System design

The dual-function system consists of a refrigeration compartment on one side and an heating compartment on the other, both powered by Peltier modules. The design includes:

Peltier modules: four tec1-12706 Peltier modules (60w each) were used to provide both heating and cooling.

Thermal management: aluminum heat sinks and cooling fans were installed to dissipate heat from the heating side, while Thermal insulation materials were used to separate the two compartments.

Two Compartments or One Flexible Compartment: Design a compartment (or separate compartments) with insulation. If using a single compartment, it should have the capability to switch between heating and cooling based on the current flow in the thermoelectric module. Fan for Air Circulation: Inside the compartment, use a fan to circulate the air for uniform temperature distribution.

Thermal Management

Heat Dissipation: In cooling mode, the hot side of the TEM must effectively dissipate heat into the surrounding environment to ensure proper cooling of the cold side. A heat sink and fan can help with this.

Efficient Insulation: Minimize heat loss from the insulated compartment to maintain a stable internal temperature.

Safety and Efficiency Considerations

Overcurrent Protection: Use fuses or current-limiting circuits to protect the TEM from excessive current, which could damage the module.

PWM Control: To optimize power consumption, use pulse-width modulation (PWM) to adjust the power supplied to the TEM, allowing it to operate at lower currents when full cooling or heating isn’t needed.

Fail-safe Temperature Limits: Implement software-controlled upper and lower temperature limits to prevent overheating or overcooling.

Use Cases

Refrigeration: For keeping food, beverages, or other items cool within a defined temperature range (e.g., 4°C-10°C).

Heating: For warming purposes, such as keeping food or beverages warm (e.g., 30°C-50°C)

1. Heat Absorbed (Qc):

$$Q_c = \alpha \cdot I \cdot T_c - \frac{1}{2} I^2 \cdot R - K \cdot (T_h - T_c)$$

Table. 1 Showing heat absorbed (Qc)

Input parameters	Corresponding values
α	0.04
V/KR	1.2 ohms
∧T	30 k
K	1.5 W/K
I	6A
T	300K
tc	5*c
th	25*c

2. Power (P)

P =V*I

Table 2. Showing power (P)

Input parameters	Corresponding values
V	12V
I	6A

3.Coefficient of Performance (COP):

$$COP = \frac{Q_c}{Qh-Qc}$$

The COP is a measure of the efficiency of cooling or heating systems. It is defined as the ratio. Of heat transferred to electrical power input.

Table 3. showing Coefficient of Performance (COP)

Input parameters	Corresponding values
Q	5.4W
P	72W

This shows Peltier cooling process is less efficient, which is typical for thermoelectric systems. For heating, since electrical input also contributes directly to heating: Heating with Peltier modules tends to be more efficient than cooling.

4. Time required to reach desired temperature:

$$t= \frac{m\times c\times \Delta T}{Q}$$

Table 4. showing Time required to reach desired temperature

Input parameters	Corresponding values
m	0.2kg
c	1005 J/kg*c
∧T	20*c
Q	5.4 W

5. Energy Consumption:

Energy Consumption over a given period is calculated using:

E = P × t

Table 5. showing Energy Consumption:

Input parameters	Corresponding values
P	72W
t	1hr

Results and discussion

Table. 1 Results and discussion

Temperature difference (*C)	Current (A)	Voltage (V)	Power (W)
0	0	0	0
10	1.7	3.5	6
20	2.4	5.5	13
27	2.8	6.5	18.5
30	3	7.3	22
40	3.6	8.5	30.5
50	4.2	10	44
60	4.7	11.5	54

Fig. 1 Current, Voltage, Power vs Temperature.

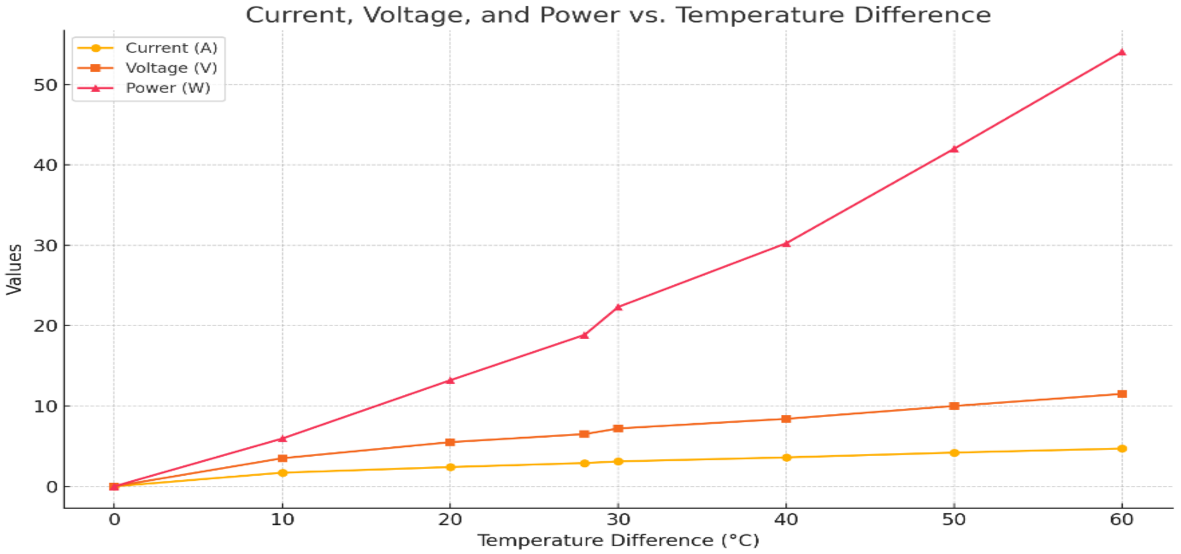
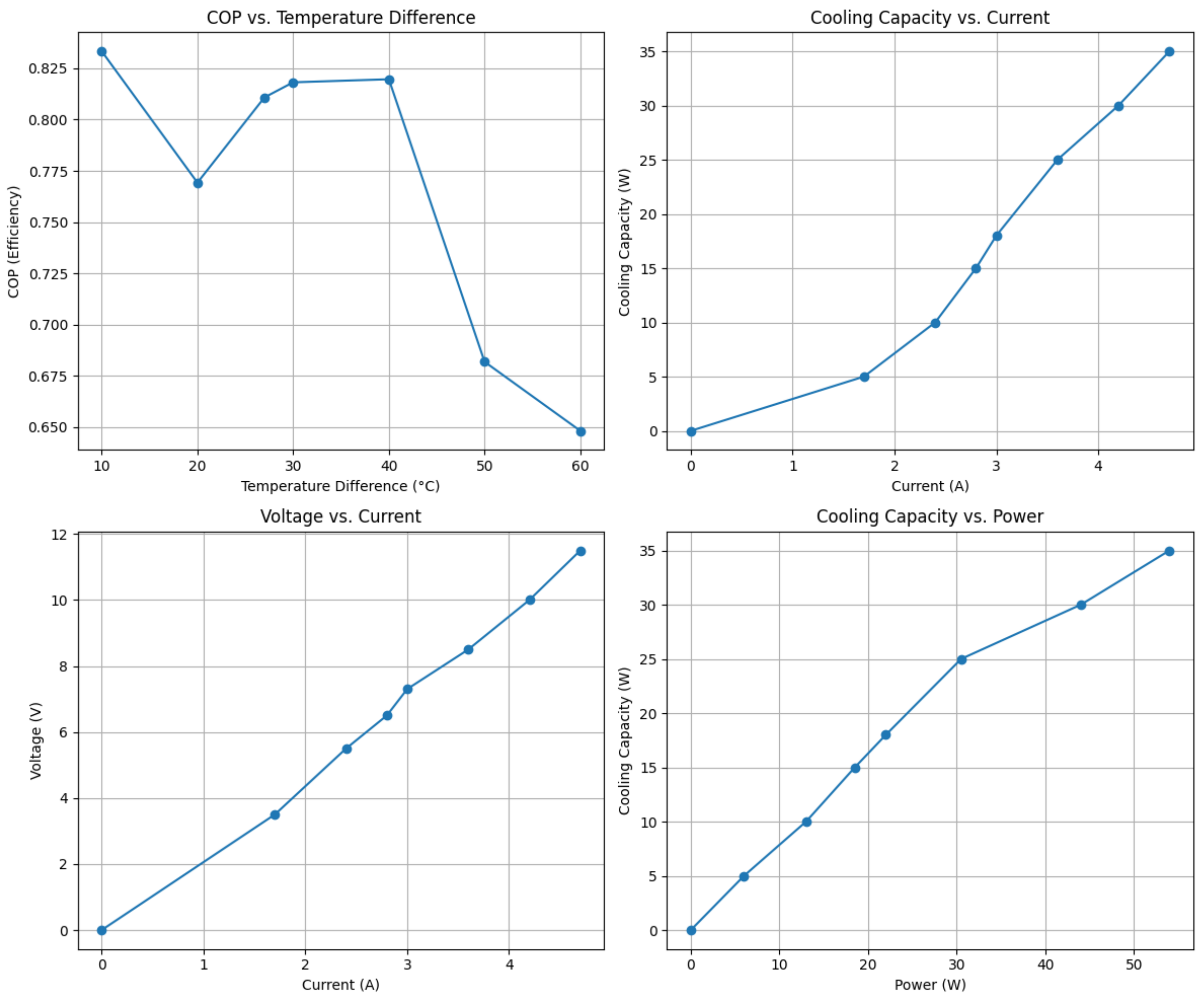


Table. 2 Results and discussion-

Temperature Difference (*C)	Current (A)	Voltage (V)	Power (W)	QC (W)	TH (*C)	COP
0	0	0	0	0	30	0
10	1.7	3.5	6	5	35	0.833333
20	2.4	5.5	13	10	40	0.769231
27	2.8	6.5	18.5	15	47	0.810811
30	3	7.3	22	18	50	0.818182
40	3.6	8.5	30.5	25	60	0.819672
50	4.2	10	44	30	70	0.681818
60	4.7	11.5	54	35	80	0.648148

Fig. 4 COP vs Temperature Difference
Fig. 5 Cooling capacity vs Current
Fig. 6 Voltage vs Current
Fig. 7 Cooling capacity vs Power



The graphs illustrate the relationship between various parameters of a Peltier refrigerator:

Temperature Difference vs. Current: As the temperature difference increases, the current required to maintain that difference also increases. The relationship appears to be non-linear, with the current increasing more rapidly at higher temperature differences.

Temperature Difference vs. Voltage: Similar to the previous graph, the voltage required increases with the temperature difference. Again, the relationship is non-linear, with voltage increasing more rapidly at higher temperature differences.

Temperature Difference vs. Power: The power consumption of the Peltier refrigerator increases with the temperature difference. The relationship is non-linear, with power consumption increasing more rapidly at higher temperature differences. These graphs provide insights into how the Peltier refrigerator's performance varies with different operating conditions.

COP vs Temperature Difference: The Coefficient of Performance (COP) of a Peltier module decreases as the temperature difference between the hot and cold sides increases, following an inverse relationship.

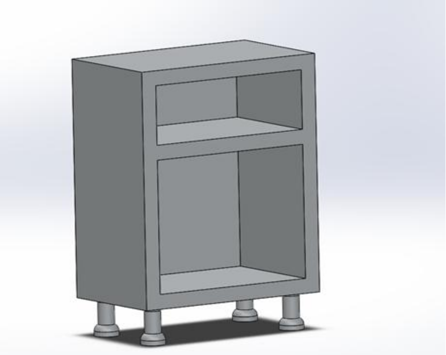
Cooling capacity vs Current: The **cooling capacity** of a Peltier module is directly proportional to the applied current. As the current increases, the amount of heat transferred from the cold side (cooling capacity) also increases, up to a certain point. However, beyond a certain current, the efficiency may decrease due to increased heat dissipation on the hot side.

Voltage vs Current: The relationship between **voltage** and **current** in a Peltier module is governed by Ohm's Law, where the current increases with the applied voltage, assuming the resistance of the module remains constant.

Cooling capacity vs Power: The **cooling capacity** of a Peltier module is directly proportional to the **power input**. As the power supplied to the module increases, the cooling capacity also increases, up to a certain point. However, beyond a specific power level, the efficiency may decrease due to higher heat dissipation and electrical losses.

4. SOLID WORKS GEOMETRY

FIG.A. SOLIDWORKS DIMENSIONSAL MODELLING OF COMPARTMENT



Dimensions:

Overall Exterior Dimensions: Approximately 50 cm (height) x 40 cm (width) x 30 cm (depth).

Compartment Breakdown

1. Cooling Compartment (24 liters):
   Interior Dimensions: ~40 cm (height) x 30 cm (width) x 20 cm (depth).

2. Heating Compartment (10 liters):
   Interior Dimensions: ~25 cm (height) x 30 cm (width) x 15 cm (depth).

FIG.B. THERMAL ANALYSIS OF PELTIER MODUL SOLID WORKS

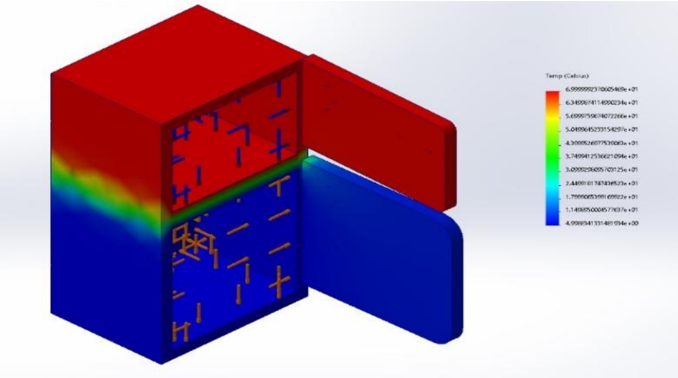


FIG.C. THERMAL ANALYSIS OF PELTIER MODULE ON SOLID WORKS

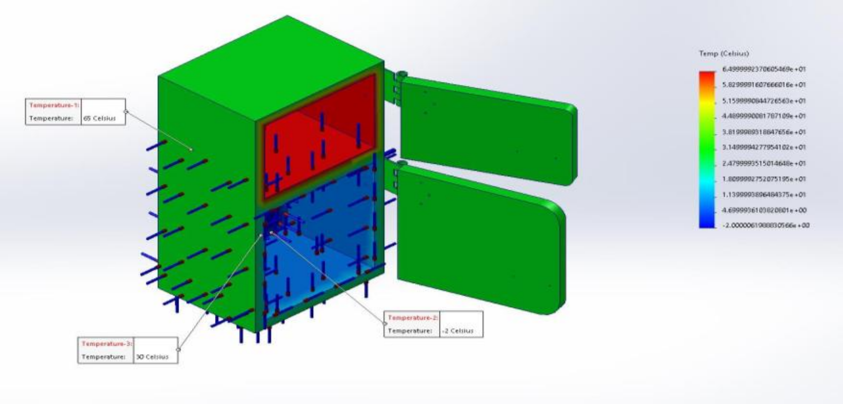
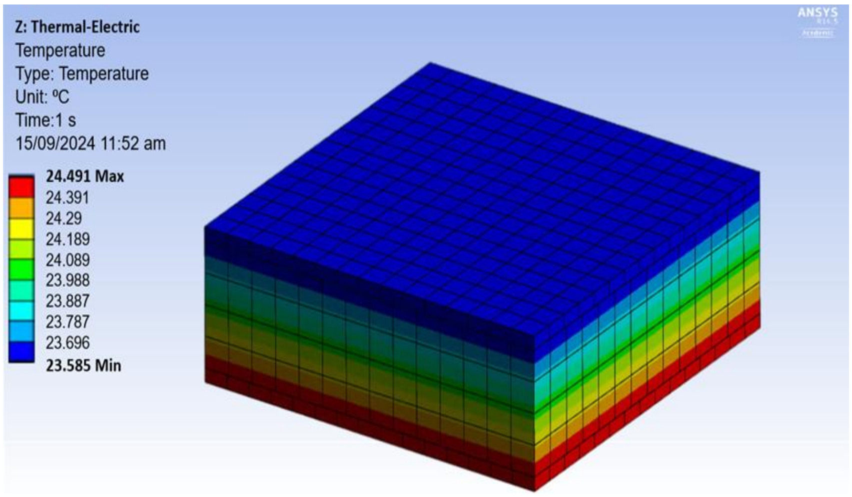


FIG.D. TEMPERATURE DIFFERENCE IN A PELTIER MODULE



1.Combined system with Peltier modules, insulation (polyurethane foam), and heating elements (ceramic for heating).
Boundary Conditions:
Refrigerator set point: 5°C
Heating set point: 150°C
Ambient temperature: 25°C

2.Results: Refrigerator Section (Cooling):
Max Temperature: 8°C (near door area)
Min Temperature: 4°C (center of the compartment)
Conclusion: Slight temperature variation due to imperfect insulation, but overall cooling is effective. Peltier modules maintained within range, minor heat loss near insulation edges.

3.Results: Heating Section (Heating):
Max Temperature: 155°C (center)
Min Temperature: 140°C (near outer walls)
Conclusion: Uniform temperature achieved across the heating with minor heat leakage. Ceramic material helped contain heat effectively.

4.Insulation Effectiveness:
Heat transfer between heating and refrigerator reduced by 30% with dual-layer insulation and air gap.
Conclusion: Insulation materials (polyurethane for refrigerator, ceramic for heating) effectively limit heat exchange, maintaining desired temperatures in both sections.

5.Peltier Module Analysis:
Thermal Gradient: Achieved a stable temperature gradient across the module (hot side 70°C, cold side 5°C).
Efficiency: Peltier modules performed efficiently under simulated conditions, but performance slightly degraded near the insulation gaps.

6.Next Steps:
Further optimization of insulation at edges to reduce heat leakage.
Improve Peltier-cooling efficiency by testing additional module configurations.

5.Components specifications

1. Module: TEC1-12706

Cooling Capacity: ~50–60W per module (depending on chosen model)
Heating Capacity: ~50–60W (when polarity is reversed)
Voltage: 12V DC
Current: 6A (maximum)
Operating Temperature Range: -40°C to 180°C

2. Power Supply

Type: 12V DC power supply (regulated)
Output Power: 100–150W (depending on the number of Peltier modules used)
Input Voltage: 110V or 220V AC (depending on the local power standard)
Output Voltage: 12V DC
Maximum Current: 10–15A

3. Temperature Range

Refrigeration Mode: 5°C to 10°C (maintained in the cooling chamber)
Heating Mode: Up to 100°C (for heating)
Control Accuracy: ±2°C

4. Heat Sink and Fan

Heat Sink Size: Aluminum heat sink (size optimized for Peltier module heat dissipation)
Fan: 12V DC, 0.5A, 80mm diameter, 2500–3000 RPM
Airflow: 40–50 CFM (for efficient heat transfer on both sides of the Peltier module)

5. Control System

Digital display (LCD or OLED) to show temperature and mode
Push buttons or touchscreen for mode and temperature selection
Temperature Sensor: NTC thermistors or digital temperature sensors (e.g., DS18B20)
Relay or Solid-State Switches: For controlling current direction through the Peltier modules, switching between heating and cooling modes.

6. Insulation

Type: High-density foam or fiberglass insulation (to minimize heat loss)
Thickness: 25–50mm (depending on performance and space constraints)

7. Structural Specifications

Chamber Size: 10–15 liters capacity for the cooling/heating compartment
Outer Dimensions: Depends on final design, typically around 300mm x 300mm x 300mm
Material: Lightweight, thermally insulated materials (e.g., plastic or metal casing with foam insulation)

8. Energy Efficiency

Standby Power Consumption: Less than 1W
Active Power Consumption: ~60W to 100W (depending on the number of Peltier modules and operating mode)
Efficiency: Coefficient of Performance (COP) of around 1 for cooling mode, and higher for heating mode due to better heat dissipation.

9. Safety Features

Overcurrent Protection: Fuses or current limiters in the power supply
Overheating Protection: Automatic shutdown if temperatures exceed safe levels.
User Safety: Insulated exterior to prevent accidental burns during heating mode

10. Estimated Lifespan

Peltier Module Lifespan: 20,000–50,000 hours (depending on usage and heat dissipation)
Fan Lifespan: 30,000 hours at optimal operating condition

6.Discussion

The results of this study on a two-in-one refrigeration and heating system using Peltier modules reveal valuable insights into both the opportunities and limitations of thermoelectric technology in practical applications. While the Peltier module is an attractive option due to its ability to provide both cooling and heating with no moving parts, its inherent inefficiencies present several challenges that must be addressed.

Performance of Peltier Modules in Dual Functions:

The ability of the Peltier module to efficiently switch between heating and cooling functions is one of its key advantages. The system designed in this research demonstrated reasonable performance in both modes, particularly for small-scale applications where compactness and quiet operation are prioritized. The reversal of current to switch between cooling and heating was straightforward and responsive, allowing for precise temperature control. However, the overall performance was hindered by the module's limited cooling capacity and temperature differential. The maximum cooling performance was restricted due to the heat generated on the hot side of the module, which required effective dissipation for sustained operation. This highlights the critical role of thermal management in improving the system's efficiency and effectiveness. Without adequate heat sinks or cooling systems, the module's efficiency rapidly declines, limiting its usefulness in larger or high-demand applications.

Energy Efficiency:

One of the major findings of the study was the relatively high-energy consumption of the system compared to traditional heating and cooling methods. Although Peltier modules offer the advantage of compact size and versatility, they operate at low efficiency, particularly when large temperature differentials are required. The system's energy consumption during both cooling and heating phases was Significant, making it less competitive with other methods that are more energy-efficient, such as vapor-compression refrigeration. Addressing the energy efficiency of Peltier modules is essential if they are to be considered a viable alternative in applications where energy savings are critical. Future research should focus on improving the efficiency of the thermoelectric materials used in Peltier modules, such as exploring advanced semiconductor materials or utilizing nanotechnology to enhance thermoelectric performance.

Thermal Management Challenges:

The heat dissipation challenge emerged as a critical factor in system performance.

For the Peltier module to work effectively, excess heat on the hot side must be efficiently removed, especially in cooling mode. Insufficient heat dissipation can lead to overheating, which reduces the cooling capacity and shortens the lifespan of the module. In this study, the use of heat sinks and cooling fans helped manage the thermal load, but the system still struggled with maintaining an optimal temperature differential under sustained operation. Thermal management improvements are essential for enhancing the overall performance of Peltier-based systems. Techniques such as liquid cooling, advanced heat exchangers, or phase change materials could be explored to mitigate this issue. Further optimization of the heat sink design and more efficient methods of transferring heat away from the module are necessary to improve reliability and efficiency.

Environmental and Practical Implications:

The environmental benefits of using Peltier modules are significant, particularly in the elimination of harmful refrigerants commonly used in vapor-compression systems. This makes Peltier-based systems an appealing option for reducing environmental impact, especially in applications that prioritize sustainability. Additionally, the solid-state nature of Peltier modules means there are no moving parts, which reduces the risk of mechanical failure, increases the system's lifespan, and makes it suitable for portable and rugged applications. However, the practical implications of the module’s low efficiency and high energy consumption limit its application in high-performance environments. While suitable for small, low-power systems such as personal cooling devices or small-scale climate control, the technology is currently less competitive in larger industrial or residential applications where higher efficiency and greater cooling capacity are needed.

Future Directions:

Moving forward, research should focus on overcoming the efficiency barrier of Peltier modules by investigating more advanced thermoelectric materials and exploring hybrid systems that combine Peltier technology with other cooling and heating. methods. For example, integrating Peltier modules with solar panels or other renewable energy sources could mitigate the issue of high-power consumption. Additionally, developing intelligent control systems to optimize power usage and heat management could further enhance system performance.Exploring new materials, such as nanostructured thermoelectric compounds, could significantly improve the performance of Peltier modules by increasing their See beck coefficient and improving their energy conversion efficiency. Another area of interest could be designing more effective and affordable thermal management solutions that reduce the overall size, cost, and complexity of the system.

7.Conclusion

The research on a two-in-one refrigeration and heating system using Peltier modules highlights both the potential and limitations of thermoelectric technology in providing a compact and environmentally friendly solution for temperature control. The system successfully demonstrated the ability to switch between cooling and heating functions within a single unit, offering a significant advantage over conventional systems that require separate devices and often involve the use of harmful refrigerants. The key findings show that Peltier modules can be applied to various small-scale and portable applications, such as personal cooling and heating devices, automotive climate control, and niche. household appliances. The compactness and solid-state nature of the Peltier module make it attractive for applications where space, noise, and environmental impact are critical factors. However, the study also identified critical challenges. The low energy efficiency of Peltier modules remains a major limitation, with significant power consumption required for effective heating and cooling, especially over prolonged periods. Additionally, thermal management issues such as heat dissipation and maintaining temperature stability need to be addressed to make these systems more practical for widespread use. The system's performance was found to be highly dependent on the effectiveness of heat sinks and other cooling mechanisms to manage the heat produced by the Peltier modules. To fully unlock the potential of Peltier-based dual-function systems, future work should explore advanced materials with higher thermoelectric efficiency, such as new semiconductor compounds or nanostructured materials. Optimization of system design, including innovative thermal management techniques and smart control systems, will also be crucial in overcoming the current limitations. In conclusion, while the Peltier module offers a promising path forward for creating multifunctional thermal systems, significant advancements are needed in both efficiency and system design to enable large-scale adoption. The research presented here lays the groundwork for further exploration into sustainable and versatile heating and cooling solutions, with the potential to reduce energy consumption and environmental impact in a range of applications.

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