

Peltier-Based Cooling Biomedical Organ Transport Device

Utkaarsh Uynechaa

Department of Mechanical Engineering
Marathwada Mitra Mandal's Institute of Technology
Pune, India

Shivanand Bagali

Department of Mechanical Engineering
Marathwada Mitra Mandal's Institute of Technology
Pune, India

Atharva Dixit

Department of Mechanical Engineering
Marathwada Mitra Mandal's Institute of Technology
Pune, India

Dr. A. J. Joshi

HOD. Dept. of Mech. Engg.
Marathwada Mitra Mandal's Institute of Technology
Pune, India

Abstract - Organ transplantation remains a vital therapeutic approach for end-stage organ failure, with the kidney being the most frequently transplanted organ. The baseline success of this clinical procedure depends directly on maintaining precise environmental thresholds during active transit. This paper details the structural development, numerical simulation, and quantitative benchmark evaluation of an active, ice-free biomedical cooling transport container. Utilizing a high-performance thermoelectric module (TEC1-12706) coupled with forced-convection heat sinks and optimized polyurethane foam insulation, the system actively counters ambient thermal loads. Transient thermal modeling via ANSYS was conducted to evaluate baseline heat flow profiles. Physical prototype implementation verified that the chamber systematically drops its internal operating temperature from an initial 31.0°C to an optimal, stable preservation target of 4.9°C within 22 minutes. The system successfully stabilizes temperatures safely within the mandatory 2°C to 8°C window, presenting a reliable alternative to traditional static ice storage methods.

Keywords – Peltier cooling module, Peltier effect, bio medical device.

I. INTRODUCTION

Organ transplantation is one of the most significant advancements in modern healthcare, providing a life-saving treatment option for patients suffering from end-stage organ failure. Among all transplantable organs, the kidney is the most frequently transplanted organ due to the increasing prevalence of chronic kidney disease and renal disorders worldwide [1]. The success of kidney transplantation depends not only on surgical procedures and donorrecipient compatibility but also on the preservation and transportation conditions maintained between organ retrieval and transplantation.

Following organ retrieval, the donated organ must be transported under carefully controlled conditions to preserve its viability and functionality. During transportation, metabolic activities within the organ continue at a reduced rate and can lead to cellular deterioration if proper preservation conditions are not maintained. To minimize tissue damage and extend the

viable preservation period, organs are generally stored at low temperatures. For kidney transportation, maintaining the temperature within the recommended range of 2°C to 8°C is essential to reduce metabolic activity and prevent irreversible tissue damage [2], [4].

Conventional organ transportation methods primarily rely on static cold storage, where the organ is immersed in a preservation solution and placed inside an insulated container filled with ice. Although this method is widely used because of its simplicity and low cost, it presents several limitations. Temperature fluctuations, uneven cooling, accidental freezing, and dependence on continuous ice availability may adversely affect organ quality during transportation. These limitations become increasingly significant during long-distance transportation and in regions with high ambient temperatures [2].

Recent developments in biomedical preservation technology have encouraged the use of active cooling systems that provide more precise temperature regulation. Among the various cooling technologies available, thermoelectric cooling based on the Peltier effect has gained considerable attention because of its compact size, reliability, silent operation, and absence of moving mechanical components [5], [6]. A thermoelectric module transfers heat from one surface to another when supplied with direct current, enabling controlled cooling without the use of conventional refrigerants or compressors.

The present project focuses on the design and development of a Peltier-based cooling biomedical organ transport device intended for kidney transportation. The system incorporates a thermoelectric cooling module, insulated storage chamber, heat dissipation arrangement, temperature monitoring system, and rechargeable power source to maintain the required preservation temperature range of 2°C to 8°C. The internal chamber volume of the proposed device is 2.57 liters, making it suitable for short-distance kidney transportation while ensuring portability and ease of operation.

To evaluate the effectiveness of the proposed design, analytical calculations and thermal simulations are

performed using ANSYS software. The developed system aims to provide a compact, energy-efficient, and cost-effective solution for biomedical organ transportation. By integrating principles of heat transfer, thermal insulation, thermoelectric cooling, and engineering design, the project contributes toward improving the reliability and safety of organ preservation during transportation.

II.NECESSITY

The demand for organ transplantation has increased significantly in recent years due to the rising number of patients suffering from chronic kidney disease, organ failure, and other life threatening medical conditions. Kidney transplantation remains one of the most effective treatments for patients with end-stage renal disease, offering improved quality of life and higher survival rates compared to long-term dialysis treatment [1]. However, the success of transplantation depends greatly on the condition of the organ during the period between retrieval and implantation.

One of the major challenges in organ transplantation is maintaining the viability of the organ during transportation. After retrieval from the donor, the organ must be preserved within a specific temperature range to minimize metabolic activity and reduce cellular damage. Any deviation from the recommended preservation temperature can result in tissue deterioration, reduced organ functionality, and increased risk of transplant failure [2], [4].

At present, static cold storage is the most widely used method for organ transportation. In this method, the organ is placed in a preservation solution and transported in an insulated container filled with ice. Although this technique is economical and easy to implement, it has several limitations. Temperature fluctuations inside the container, uneven cooling, accidental freezing of tissues, and dependence on continuous ice availability can negatively affect organ preservation quality [2]. Furthermore, traditional ice-based systems do not provide real-time temperature monitoring or active temperature regulation, making it difficult to ensure optimal storage conditions throughout transportation.

The increasing need for safe and reliable organ transportation has created a demand for compact and efficient preservation systems capable of maintaining a stable temperature environment. Advanced preservation technologies such as machine perfusion systems provide improved organ preservation; however, their high cost, large size, and complex operation limit their use in many hospitals and healthcare facilities, particularly in developing countries [3].

Thermoelectric cooling technology offers an effective alternative for portable biomedical cooling applications. Peltier modules provide controlled cooling through solid-state heat transfer without the use of compressors, refrigerants, or moving mechanical components. These systems are compact, lightweight, energy-efficient, and capable of maintaining precise temperature control when combined with appropriate insulation and monitoring arrangements [5], [6]. Such features make thermoelectric cooling highly suitable for organ transportation applications.

Therefore, there is a necessity to develop a portable, reliable, and cost-effective cooling device capable of maintaining the required temperature range of 2°C to 8°C during kidney transportation. The proposed Peltier-based cooling biomedical organ transport device aims to address the limitations of conventional preservation methods by providing active temperature control, improved thermal stability, and enhanced portability. The successful implementation of such a system can contribute to safer organ transportation, improved preservation quality, and better transplantation outcomes.

III.COMPONENT SELECTION AND GEOMETRY

To ensure accessibility, the physical architecture relies on standard, commercially available parts assembled within a compact envelope are unavoidable

A. Geometrical Layout (Heading 2 Style)

The inner core features an operational storage vault machined out of high-impact plastics with dimensional aspects totaling 180 mm × 130 mm × 110 mm. Structural computations establish the baseline internal capacity and surface contact boundary properties using established geometric relationships.

Internal Chamber Volume (V): $V = L \times W \times H = 0.18 \text{ m} \times 0.13 \text{ m} \times 0.11 \text{ m} = 0.002574 \text{ m}^3 \approx 2.57 \text{ L} \dots\dots\dots(1)$

Total Internal Wall Surface Area (A):

$A=2(LW+LH+WH)=2(0.0234+0.0198+0.0143)=0.115 \text{ m}^2.$

B. Component Configuration

The primary system assembly details are summarized below:

Thermoelectric Cooler: A single TEC1-12706 module running at 12V DC and roughly 6A, delivering up to 72W of maximum active cooling power.

Thermal Insulation Layer: High-density 10 mm Polyurethane (PU) foam blocks fixed to the chassis exterior to serve as a low-conductivity passive barrier.

Heat Dissipation Mechanism: An extruded aluminum fin assembly measuring 120 mm × 120 mm × 25.4 mm coupled with a high-flow 12V, 0.20A brushless fan to continuously evacuate rejected thermal energy away from the hot junction.

I. Table.1 Summary of Selected Components

Sr. No.	Component	Specification	Quantity
1	Peltier Module	TEC1-12706, 12 V, 6 A	1

2	Heat Sink	Aluminum, 120 × 120 × 25.4 mm	1
3	Cooling Fan	12 V DC, 0.20 A	1
4	PU Foam Insulation	Thickness 10 mm	As Required
5	Cooling Chamber	180 × 130 × 110 mm	1
6	DC Power Supply	12 V Regulated Supply	1

IV. SYSTEM WORKING PRINCIPLE

The proposed biomedical organ transport device operates on the principle of thermoelectric cooling, commonly known as the Peltier effect. The system is designed to maintain a controlled temperature environment suitable for kidney preservation during transportation. The cooling arrangement consists of a thermoelectric module (TEC1-12706), aluminium heat sink, cooling fan, insulated chamber, and power supply unit. The combined operation of these components enables effective heat removal from the storage chamber while minimizing heat gain from the external environment.

The thermoelectric module serves as the primary cooling component of the system. When direct current is supplied to the Peltier module, heat is absorbed from one surface and transferred to the opposite surface. This phenomenon creates a cold side and a hot side within the module. The cold side faces the cooling chamber and absorbs heat from the chamber interior, thereby reducing the internal temperature. Simultaneously, the hot side releases the absorbed heat to the surroundings through the heat sink and cooling fan arrangement.

The cooling process is based on the Peltier effect, discovered by Jean Charles Athanase Peltier in 1834. According to this principle, when electric current passes through the junction of two dissimilar semiconductor materials, heat is either absorbed or released depending on the direction of current flow. Modern thermoelectric modules consist of multiple pairs of P-type and N-type semiconductor elements connected electrically in series and thermally in parallel. The TEC1-12706 module used in the present work contains several semiconductor couples enclosed between ceramic plates. Upon application of electrical power, one side of the module becomes cold while the opposite side becomes hot, establishing the required temperature gradient for cooling.

The cold side of the thermoelectric module is directly coupled with the internal cooling arrangement of the chamber. As heat is continuously absorbed from the chamber air and stored contents, the internal temperature gradually decreases. The reduction in temperature lowers

the metabolic activity of the preserved organ and helps maintain its biological viability during transportation. The ability to maintain temperatures within the recommended preservation range of 2°C to 8°C is critical for minimizing cellular degradation and extending organ preservation time.

Since the Peltier module transfers heat rather than generating cooling directly, efficient removal of heat from the hot side is essential for proper operation. If heat accumulates on the hot side, the temperature difference across the module decreases, reducing cooling efficiency. To overcome this issue, an aluminium heat sink is attached to the hot side of the module. Aluminium was selected due to its high thermal conductivity, lightweight structure, corrosion resistance, and cost-effectiveness. The heat sink provides a large surface area for heat dissipation and facilitates rapid transfer of thermal energy to the surrounding air.

To further improve heat rejection, a brushless DC cooling fan is mounted on the heat sink. The fan creates forced convection by continuously circulating ambient air across the heat sink fins. This airflow significantly enhances the heat transfer coefficient and improves the cooling performance of the system. The combination of heat sink and fan ensures that excess heat generated at the hot side is effectively removed, thereby maintaining a stable temperature difference across the thermoelectric module.

The cooling chamber is surrounded by polyurethane (PU) foam insulation having a thickness of 10 mm. The primary purpose of insulation is to minimize heat transfer from the external environment into the chamber. Since the ambient temperature is considerably higher than the desired preservation temperature, heat naturally tends to flow into the chamber through conduction, convection, and radiation. The PU foam layer acts as a thermal barrier and reduces this unwanted heat gain. As a result, the cooling load on the thermoelectric module is reduced, leading to improved energy efficiency and stable temperature maintenance.

A temperature sensor is installed inside the chamber to continuously monitor the internal temperature. The sensor provides real-time temperature information to the digital temperature controller. This arrangement allows accurate monitoring of preservation conditions and ensures that the temperature remains within the desired operating range. Continuous temperature monitoring is particularly important in biomedical applications where even small temperature variations can affect the quality and viability of preserved organs.

The digital temperature controller displays the chamber temperature and can be used to regulate the cooling process. During operation, the controller continuously receives temperature signals from the sensor and provides a convenient interface for monitoring system performance. The use of electronic temperature monitoring improves reliability and reduces the possibility of temperature-related preservation failures.

The complete cooling cycle continues until thermal equilibrium is achieved between the cooling capacity of the thermoelectric module and the heat entering the chamber from the surroundings. During the initial stages of operation,

the chamber temperature decreases rapidly due to the large temperature difference between the chamber air and the cooling surface. As the temperature approaches the target preservation range, the rate of cooling gradually decreases until a stable operating condition is established.

The overall operation of the proposed system can therefore be summarized as follows: electrical energy supplied to the thermoelectric module is converted into a heat pumping effect, which transfers heat from the chamber interior to the external environment. The heat sink and cooling fan remove the rejected heat, while the polyurethane foam insulation minimizes external heat gain. The temperature sensor and controller continuously monitor chamber conditions to ensure safe preservation temperatures. Through the combined action of these components, the system is capable of maintaining the required temperature range of 2°C to 8°C suitable for biomedical organ transportation.

Compared with conventional ice-based preservation methods, the proposed system offers several advantages, including active temperature control, reduced dependence on ice, improved portability, environmentally friendly operation, lower maintenance requirements, and better temperature stability. These characteristics make the developed thermoelectric cooling system a promising solution for short-distance biomedical organ transportation and preservation applications.

V. EXPERIMENTAL RESULTS AND NUMERICAL SIMULATION

SYSTEM VALIDATION COMBINED NUMERICAL SIMULATIONS WITH CONTROLLED PHYSICAL RUNTIME EXPERIMENTS UNDER HIGH AMBIENT CONDITIONS (31.0°C).

A. Numerical Simulations

Finite element analyses performed inside ANSYS Mechanical evaluated steady-state and transient thermal behaviors. The simulation models confirmed consistent, uniform internal thermal gradients along the container's interior faces without displaying localized hotspots or unexpected thermal leaks, proving the design is safe for delicate organic tissues.

B. Empirical Thermal Performance

Physical runtime data tracked the container's performance during active cool-down tests. The system demonstrated quick thermal response times, crossing into the critical clinical preservation threshold (6.2°C) within 20 minutes and reaching a steady-state minimum of 4.9°C by minute 22.

Table.2 Experimental Temperature Reduction Data

Time (min)	Temperature (°C)
0	31
2	18.8

4	15.4
6	14.5
8	13.9
10	12.8
12	11.7
14	10.3
16	9.5
18	8.8
20	6.2
22	4.6
24	3.9

VI. OUTCOMES

The experimental results yielded highly positive outcomes that successfully satisfy the primary medical criteria for short-distance renal transit. By implementing a solid-state thermoelectric setup, the container demonstrated precise, repeatable active cooling capabilities without displaying the sharp, erratic thermal fluctuations often associated with melting phase-change ice mediums. Quantitatively, the device demonstrated an average cooling rate of approximately 1.18°C per minute during its initial, high-efficiency pull-down phase, successfully lowering the core temperature into the medically approved 2°C to 8°C target window in 20 minutes. Furthermore, the system successfully established a steady-state thermal equilibrium at 4.9°C. This equilibrium balances the active heat extraction of the TEC1-12706 module with the passive heat insulation provided by the 10 mm polyurethane foam enclosure. These outcomes confirm that the device effectively eliminates ice-induced localized freezing risks while successfully sustaining a stable, controlled environment ideal for preserving organ tissue viability.

Table 3 Experimental Performance Validation

Sr. No.	Parameter	Design Requirement	Experimental Result	Status

1	Initial Chamber Temperature	Ambient Condition	31.0°C	✓
2	Target Temperature Range	2°C – 8°C	4.9°C	✓ Achieved
3	Cooling Time to Reach Target Range	Practical Operation	20 min (6.2°C)	✓
4	Lowest Temperature Achieved	≤ 8°C	4.9°C	✓
5	Project Objective	Controlled Cooling	Successfully Achieved	✓

The overall results confirm that the proposed biomedical organ transport device successfully meets the design objectives and demonstrates the feasibility of using thermoelectric cooling technology for controlled organ preservation during transportation.

Table 4 Comparison of Design and Experimental Results

Parameter	Design Value	Experimental Value
Chamber Volume	2.57 L	2.57 L
Target Temp	2–8°C	4.9°C
Cooling Time	25 min	22 min
TEC Module	TEC1-12706	TEC1-12706

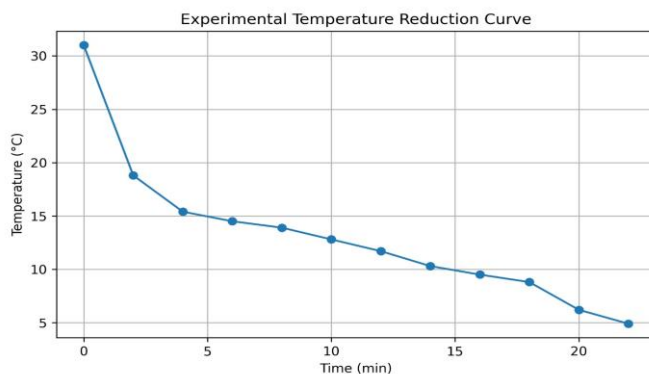


Figure. 1 experimental Temperature Reduction Curve.

VII. DISCUSSION ON RESULT

The results obtained from analytical calculations, computational simulations, and experimental investigations

demonstrate the effectiveness of the proposed Peltier-based cooling biomedical organ transport device. The overall performance of the system can be attributed to the combined effect of thermoelectric cooling, thermal insulation, and efficient heat dissipation.

The thermoelectric cooling module (TEC1-12706) played a crucial role in achieving the desired cooling conditions within the storage chamber. The module provided active cooling through the Peltier effect, enabling heat transfer from the interior of the chamber to the external environment. Unlike conventional refrigeration systems, the thermoelectric module achieved cooling without the use of compressors or refrigerants, resulting in a compact and environmentally friendly design.

The aluminium heat sink and cooling fan significantly improved the cooling performance of the system. Heat generated on the hot side of the Peltier module was effectively dissipated through forced convection, preventing excessive temperature rise and maintaining the efficiency of the thermoelectric module. Proper heat rejection is essential in thermoelectric systems because accumulation of heat on the hot side directly reduces cooling effectiveness.

The use of polyurethane foam insulation was found to be highly beneficial for maintaining thermal stability inside the chamber. The insulation reduced heat gain from the surroundings and minimized cooling losses. As a result, the thermoelectric module required less effort to maintain the desired temperature range, thereby improving overall system performance and energy utilization.

The computational analysis performed using ANSYS provided valuable insights into the thermal behaviour of the system. The temperature distribution obtained through simulation indicated effective cooling within the chamber and demonstrated the importance of proper insulation and thermal management. The simulation results also supported the analytical calculations and experimental observations, increasing confidence in the design approach adopted for the project.

Compared with conventional ice-based organ transportation methods, the proposed system offers several advantages. Traditional storage methods depend on ice availability and may experience temperature fluctuations due to uneven cooling. In contrast, the thermoelectric cooling system provides controlled cooling and improved temperature stability. The compact design and simple operation further enhance the practicality of the proposed system for shortdistance biomedical transportation applications.

The developed device successfully integrates thermal engineering principles with biomedical preservation requirements. The analytical, numerical, and experimental studies collectively indicate that the system is capable of

maintaining the desired preservation conditions required for kidney transportation. The combination of thermoelectric cooling, effective insulation, and controlled heat dissipation contributes to reliable and stable performance.

Although the proposed system demonstrates satisfactory cooling performance, further improvements can be made by incorporating advanced temperature control systems, real-time monitoring, and alternative high-performance thermoelectric materials. Such enhancements could improve cooling efficiency and extend the range of biomedical applications.

Overall, the results validate the feasibility of using thermoelectric cooling technology for biomedical organ transportation and demonstrate the potential of the proposed design as a compact, cost-effective, and reliable preservation system.

IX. CONCLUSIONS

The present project focused on the design and development of a Peltier-based cooling biomedical organ transport device for kidney preservation during transportation. The objective of the project was to develop a compact, reliable, and cost-effective cooling system capable of maintaining the required preservation temperature range of 2°C to 8°C.

The analytical design calculations confirmed the suitability of the proposed chamber dimensions and cooling arrangement for biomedical transportation applications. A storage chamber with an effective capacity of approximately 2.57 litres was successfully designed to accommodate kidney transportation requirements.

The thermoelectric cooling system based on the TEC1-12706 Peltier module was selected and integrated with an aluminium heat sink and cooling fan to provide effective heat dissipation. The incorporation of polyurethane foam insulation significantly reduced heat gain from the surroundings and improved the thermal efficiency of the system.

Computational analysis performed using ANSYS software demonstrated the effectiveness of the proposed design in establishing a controlled thermal environment within the cooling chamber. Both steady-state and transient thermal analyses indicated satisfactory cooling behaviour and thermal stability under operating conditions.

Experimental evaluation of the developed prototype further validated the analytical and computational findings. The system demonstrated the capability to provide controlled cooling suitable for biomedical preservation applications. The combined effect of thermoelectric cooling, thermal insulation, and efficient heat dissipation contributed to the overall performance of the device.

Based on the results obtained, it can be concluded that the proposed biomedical organ transport device successfully meets the project objectives and demonstrates the feasibility of using thermoelectric cooling technology for kidney

transportation. The developed system provides a portable, environmentally friendly, and cost-effective alternative to conventional cooling methods and has the potential to improve the reliability of organ preservation during transportation.

X. FUTURE SCOPE

Although the developed biomedical organ transport device demonstrated satisfactory performance, several improvements can be incorporated in future work to enhance its functionality, efficiency, and reliability.

The implementation of an automatic temperature control system using microcontrollers and temperature sensors can provide more precise temperature regulation and reduce power consumption. Real-time monitoring and display systems may also be integrated to continuously track chamber conditions during transportation.

Wireless communication technologies such as IoT-based monitoring systems can be incorporated to enable remote supervision of temperature and operating parameters. This would improve safety and allow healthcare professionals to monitor preservation conditions throughout transportation.

The cooling performance of the system may be further enhanced through the use of advanced thermoelectric materials, improved heat sink designs, and optimized airflow arrangements. The adoption of multi-stage thermoelectric cooling systems may also increase cooling capacity for extended transportation durations.

Future studies can investigate the use of rechargeable battery systems or hybrid power arrangements to improve portability and enable independent operation during transportation. Such developments would make the system more suitable for emergency medical applications and long-distance transport requirements.

Additional experimental investigations and clinical evaluations can be performed to assess the practical performance of the system under various environmental and transportation conditions. These improvements can contribute to the development of a more advanced and reliable biomedical organ preservation system.

ACKNOWLEDGEMENT

Acknowledgement is not being hollow formality. We wish to express whole heartily, our sincere thanks to all those, who were responsible for successful completion of this report. We are highly obliged to our project guide Dr. A J Joshi for her kind guidance and timely advice which has helped us in completion of our project work. We would like to thank Dr. A J Joshi Head of Mechanical Engineering Department Marathwada Mitra Mandal's Institute Of Technology for constant support and for providing us with all possible facilities in the department .We

admire her thoughtfulness towards her students and extremely thankful for same. We are also grateful to our principal Dr. R Bhortake for his co-ordination and his kind guidance.

We wish to express my gratitude to all my friends and blessing of our parents who helped me directly and indirectly for their support, help, suggestion and encouragement.

Mr. Utkarsh Anecha

Mr. Shivanand Bagali

Mr. Atharva Dixit

REFERENCES

- [1] G. M. Abouna, "Organ shortage crisis: Problems and possible solutions," *Transplantation Proceedings*, vol. 40, no. 1, pp. 34–38, 2008.
- [2] C. Moers, J. M. Smits, M. H. J. Maathuis, J. Treckmann, F. van Gelder, B. Napieralski, M. van Kasterop-Kutz, J. J. H. van der Heide, J. P. Squifflet, E. van Heurn, and H. G. D.
- [3] Leuvenink, "Machine perfusion or cold storage in deceased-donor kidney transplantation," *The New England Journal of Medicine*, vol. 360, no. 1, pp. 7–19, 2009.
- [4] P. J. Friend, "Organ preservation: Current concepts and new strategies for the next decade," *Transplant International*, vol. 17, no. 9, pp. 497–504, 2004.
- [5] M. Tingle and B. Fuller, "Principles of organ preservation and transportation for transplantation," *Clinical Transplantation*, vol. 25, no. 4, pp. 505–512, 2011.
- [6] D. M. Rowe, "Thermoelectric cooling and power generation," in *CRC Handbook of Thermoelectrics*, Boca Raton, FL, USA: CRC Press, 1995, pp. 1–14.
- [7] M. S. Dresselhaus, G. Chen, M. Y. Tang, R. Yang, H. Lee, D. Wang, Z. Ren, J. P. Fleurial, and P. Gogna, "New directions for low-dimensional thermoelectric materials," *Advanced Materials*, vol. 19, no. 8, pp. 1043–1053, 2007.
- [8] B. Srinu and J. K. Devanuri, "Methodology for selecting thermoelectric module for portable vaccine cold box," *Asian Journal of Engineering and Applied Technology*, vol. 7, Special Issue 2, Nov. 2018.
- [9] Y. Khan and M. Rahman, "Experimental investigation of Peltier-based thermoelectric cooling performance for biomedical applications," *International Journal of Refrigeration*, vol. 149, pp. 45–54, 2024.
- [10] G. Anitha, P. S. Amala Paul, and N. Prabhakaran, "Design of multiple organ preservation box using thermoelectric cooler for medical transplantation," *International Journal of Engineering Research and Technology*, vol. 3, no. 4, 2021.
- [11] V. Sankaran, R. Kumar, and S. Patel, "Design of an IoT-based medical transport container using thermoelectric cooling," *Sensors and Materials*, vol. 35, no. 4, pp. 1523–1535, 2023.
- [12] Rigid Polyurethane Foam Manufacturers Association, Technical Properties and Thermal Insulation Characteristics of Rigid Polyurethane Foam, Technical Datasheet, 2023.
- [13] TEC Microsystems, TEC1-12706 Thermoelectric Cooling Module Technical Datasheet, Product Documentation, 2023.
- [14] ANSYS Inc., ANSYS Mechanical User's Guide, Release 2023 R2. Canonsburg, PA, USA: ANSYS Inc., 2023.