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Design and Performance Analysis of a Portable Refrigerator Based on a Thermoelectric Peltier

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Abstract- The increasing demand for cooling technology in modern society has contributed to environmental challenges, particularly those related to the use of refrigerants such as chlorofluorocarbons (CFCs) that can damage the ozone layer and contribute to global warming. Conventional refrigeration systems generally rely on vapor compression cycles that require chemical refrigerants and relatively high electrical energy consumption. Therefore, alternative cooling technologies that are environmentally friendly, compact, and energy efficient are needed. One promising solution is the application of thermoelectric cooling technology based on the Peltier effect. This study aims to design, construct, and evaluate the performance of a portable refrigerator based on a Peltier module. The research used a design-and-build method conducted in the Physics Laboratory of PMIPA FKIP Universitas Riau. The cooling system utilizes a TEC-12706 thermoelectric module powered by a 12-volt DC power supply combined with heatsinks, cooling fans, and thermal insulation. Experimental testing was conducted using two variations of water volume, namely 100 ml and 200 ml, to evaluate the cooling performance of the device over a period of 30 minutes. The results show that the portable refrigerator successfully reduced the temperature of 100 ml of water from 30.8°C to 28.4°C within 30 minutes, while the temperature of 200 ml water decreased from 30.8°C to 29.4°C during the same duration. These findings indicate that thermoelectric cooling is more effective for small thermal loads. The study demonstrates that portable thermoelectric refrigeration systems offer an environmentally friendly cooling alternative suitable for small-scale applications.

Keywords: *Energy efficiency; Heat transfer; Peltier module; Portable refrigerator; Temperature control; Thermoelectric cooling*

1 Introduction

Technological advancement in the modern era has significantly transformed many aspects of human life. Various innovations in transportation, communication, and household technology have been developed to improve efficiency and convenience in daily activities. Among household technologies, cooling systems such as refrigerators, air conditioners, and water dispensers play an essential role in preserving food, maintaining thermal comfort, and supporting modern lifestyles. However, despite their benefits, conventional cooling technologies often rely on chemical refrigerants that may have harmful environmental consequences (Cengel & Boles, 2015).

One of the most pressing environmental issues associated with cooling technologies is the depletion of the ozone layer caused by the release of chlorofluorocarbons (CFCs). These chemical compounds were widely used as refrigerants in refrigeration and air conditioning systems for decades due to their stability and effective cooling properties. Unfortunately, CFCs are also known to damage the ozone layer when released into the atmosphere. The ozone layer plays a crucial role in protecting the Earth from harmful ultraviolet radiation. When this layer becomes thinner, more ultraviolet radiation reaches the Earth's surface, increasing environmental and health risks (Khaznah et al., 2024).

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In addition to ozone depletion, CFCs and other refrigerant gases also contribute significantly to the greenhouse effect, which leads to global warming. Global warming refers to the gradual increase in the Earth's average temperature caused by the accumulation of greenhouse gases in the atmosphere. These gases trap infrared radiation emitted from the Earth's surface, preventing heat from escaping into space and causing an increase in global temperatures (Astutik et al., 2024). The impact of global warming is increasingly visible through rising sea levels, melting polar ice caps, extreme weather events, and disruptions in ecosystems and biodiversity (Khinanti et al., 2025).

The rapid increase in global temperatures has created new challenges for human comfort and health. In many regions, extreme heat conditions are becoming more frequent, leading to dehydration risks, decreased productivity, and other health problems. As a result, the demand for cooling technologies continues to increase worldwide. Refrigerators are among the most widely used cooling devices in households because they help preserve food and beverages by lowering temperature and slowing down microbial growth (Gumilang et al., 2023). Conventional refrigerators typically operate using a vapor compression refrigeration cycle. This system involves several main components, including a compressor, condenser, expansion valve, and evaporator. In this cycle, a refrigerant circulates through the system and undergoes phase changes between liquid and gas states. The compressor increases the pressure and temperature of the refrigerant gas, which then releases heat in the condenser. After passing through the expansion valve, the refrigerant pressure decreases, causing a temperature drop. The refrigerant then absorbs heat from inside the refrigerator through the evaporator, creating the cooling effect (Whitman et al., 2016).

Although vapor compression refrigeration systems are effective and widely used, they have several disadvantages. First, they consume relatively large amounts of electrical energy, which increases operational costs and contributes indirectly to carbon emissions from electricity production. Second, the refrigerants used in these systems may pose environmental hazards if leaks occur. Even modern refrigerants designed to replace CFCs may still contribute to global warming if released into the atmosphere (Taufiq et al., 2021). Furthermore, conventional refrigerators are generally large and not easily portable. Their size and mechanical complexity make them unsuitable for applications requiring compact and mobile cooling devices. In many situations, such as outdoor activities, small laboratories, transportation, or field research, a portable cooling system may be more practical and efficient. Therefore, the development of alternative cooling technologies that are compact, environmentally friendly, and energy efficient is becoming increasingly important (Aprilia et al., 2025). One promising alternative cooling technology is thermoelectric cooling based on the Peltier effect. Thermoelectric cooling devices operate using semiconductor materials that convert electrical energy directly into temperature differences. When an electric current flows through a thermoelectric module composed of p-type and n-type semiconductor materials, heat is absorbed on one side of the module and released on the other side. As a result, one side becomes cold while the opposite side becomes hot. This phenomenon is known as the Peltier effect (Mirmanto, 2021).

Thermoelectric cooling systems offer several advantages compared to conventional refrigeration systems. First, they do not require refrigerant gases such as CFCs or hydrofluorocarbons (HFCs), making them environmentally friendly. Second, thermoelectric modules have no moving mechanical parts, which reduces noise, vibration, and maintenance requirements. Third, their compact size allows them to be integrated into portable devices and small cooling systems. These characteristics make thermoelectric cooling particularly suitable for applications where simplicity, reliability, and environmental sustainability are priorities (Faisal et al., 2016).

From a physics perspective, thermoelectric cooling systems involve several important concepts, particularly thermodynamics and heat transfer. According to the first law of thermodynamics, energy cannot be created or destroyed but can only be converted from one form to another. In a thermoelectric cooler, electrical energy supplied to the Peltier module is converted into heat transfer energy, allowing heat to move from the cold side to the hot side of the module (Alfaris et al., 2022). The second law of thermodynamics also plays a crucial role in the operation of refrigeration systems. This law states that heat naturally flows from regions of higher temperature to regions of lower temperature. To transfer heat in the opposite direction, from a colder region to a hotter region, external work is required. In thermoelectric cooling systems, this external work is provided by electrical energy supplied to the Peltier module (Cengel & Boles, 2015).

In addition to thermodynamics, heat transfer mechanisms such as conduction and convection are also involved in the cooling process. Conduction occurs when heat flows through solid materials, such as the heatsink attached to the Peltier module. Meanwhile, convection occurs when heat is transferred through the movement of fluids, such as air circulated by cooling fans (Sulaiman, 2015; Nopriantoko, 2024). Efficient heat dissipation is essential to ensure optimal performance of thermoelectric cooling systems. Several studies have explored the application of thermoelectric cooling technology in portable refrigeration systems. Gumilang et al. (2023) demonstrated that thermoelectric modules can effectively reduce temperature in small cooling chambers when combined with appropriate heat dissipation systems. Similarly, Triyono et al. (2024) reported that portable cooling systems using Peltier modules are suitable for small-scale cooling applications such as beverage coolers or portable food storage devices.

Considering the increasing demand for environmentally friendly and portable cooling solutions, the development of a portable refrigerator based on thermoelectric technology represents an important area of research. Such systems can provide practical cooling solutions for small-scale applications while reducing environmental risks associated with conventional refrigerants. Based on these considerations, this study aims to design, construct, and evaluate the performance of a portable refrigerator based on a Peltier module. The research focuses on the design and testing of the cooling system to determine its effectiveness in reducing temperature under different experimental conditions. The results of this study are expected to contribute to the development of environmentally friendly cooling technologies that are compact, portable, and energy efficient (Liyanty et al., 2025).

2 Research Methodology

This study employed a design and development (design-build) research method to design, construct, and evaluate the performance of a portable refrigerator based on a thermoelectric Peltier module. The research was conducted in the Physics Laboratory of the PMIPA Department, Faculty of Teacher Training and Education, Universitas Riau, during May–June 2025. The design-build method was chosen because it allows researchers to systematically develop a prototype device and analyze its operational performance through experimental testing.

2.1 Research Design

The research procedure consisted of several main stages, namely literature study, system design, prototype construction, experimental testing, and data analysis. The literature study was carried out to understand the theoretical concepts related to thermoelectric cooling, heat transfer, and thermodynamics. Various references from books and scientific journals were reviewed to support the design and operational principles of the portable refrigeration system.

After the literature review stage, the next step was to design the portable refrigerator system. The design focused on integrating a thermoelectric cooling module (Peltier TEC-12706) with supporting components such as heatsinks, cooling fans, thermal insulation, and a DC power supply. The overall design aimed to produce a compact and portable cooling device capable of lowering the temperature inside a small storage chamber.

2.2 Tools and Materials

Several tools and materials were used to construct the portable refrigerator prototype. The main component of the system was a thermoelectric Peltier module TEC-12706, which functions as the primary cooling device. This module works based on the Peltier effect, where an electric current flowing through semiconductor materials creates a temperature difference between two surfaces.
Additional components used in the system included:

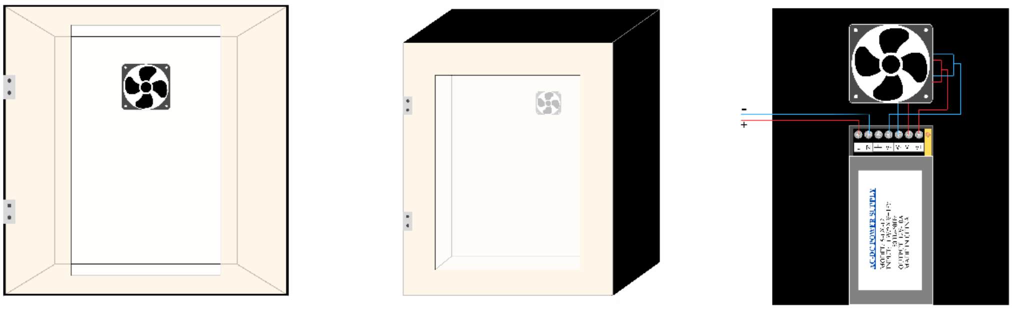
- Heatsink (98 × 98 × 25 mm) to dissipate heat from the hot side of the Peltier module.
- Secondary heatsink (40 × 60 × 18 mm) to assist heat absorption inside the cooling chamber.
- Cooling fans to enhance heat dissipation through forced convection.
- Power supply (12 V, 10 A) to provide a stable direct current required for the thermoelectric module.
- Thermal paste to improve thermal contact between the Peltier module and heatsink surfaces.
- Polystyrene box used as the refrigerator chamber because of its good thermal insulation properties.
- Digital thermometer to measure temperature changes inside the cooling chamber.
- Acrylic sheets and supporting structures to reinforce the physical construction of the device.

These components were assembled to create a portable refrigeration system capable of generating a temperature difference through thermoelectric cooling.

2.3 Prototype Construction

The construction process began with preparing the insulated cooling chamber using a polystyrene box. Polystyrene was selected because it has low thermal conductivity, which helps maintain the cold temperature inside the chamber.

The Peltier module was installed between two heatsinks. The cold side of the Peltier module was placed facing the interior of the cooling chamber, while the hot side was connected to an external heatsink equipped with a cooling fan. Thermal paste was applied between the surfaces to improve heat transfer efficiency. Two cooling fans were used in the system. One fan was installed on the external heatsink to remove heat from the hot side of the Peltier module. The second fan was installed inside the cooling chamber to distribute cold air evenly throughout the interior space. All electrical components were connected to a 12-volt DC power supply, allowing the system to operate continuously during testing.



(a) (b) (c)

Figure 1. Device design (a) Front (b) Rear (c) Side

The electronic components used in the Peltier module-based portable refrigerator are located at the rear of the refrigerator. The electronic circuit diagram can be seen in Figure 2 below.

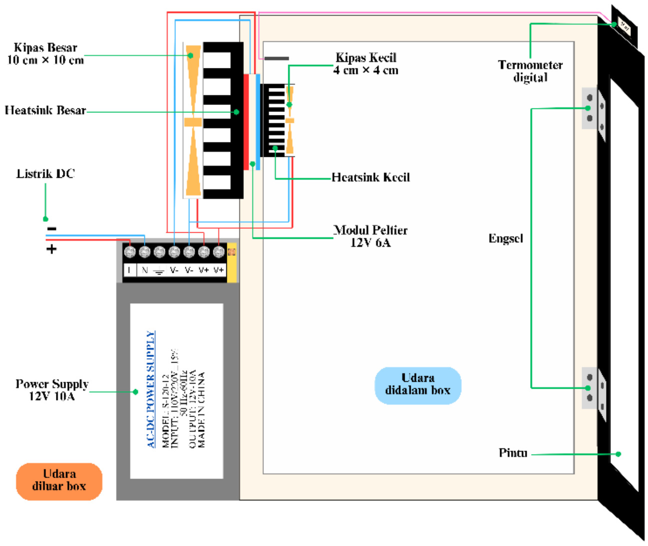


Figure 2. Electronic Circuit Schematic

2.4 Data Analysis

The collected data were analyzed quantitatively by comparing the initial and final temperatures of the water samples during the cooling process. Temperature changes were used to evaluate the cooling performance of the thermoelectric system.

The analysis also considered the influence of thermal mass (water volume) on the cooling efficiency. According to heat transfer theory, the amount of heat removed from a substance is related to its mass, specific heat capacity, and temperature change. Therefore, larger water volumes require more energy to achieve the same temperature reduction.

3 Results and Discussion

The development of the portable refrigerator based on the Peltier module successfully produced a compact cooling device designed for small-scale cooling applications. The prototype consists of several key components, including a thermoelectric module (TEC-12706), heatsinks, cooling fans, a DC power supply, thermal insulation materials, and a polystyrene cooling chamber. The device was designed with portability in mind, allowing it to be easily transported and used in various situations where conventional refrigeration systems are impractical.

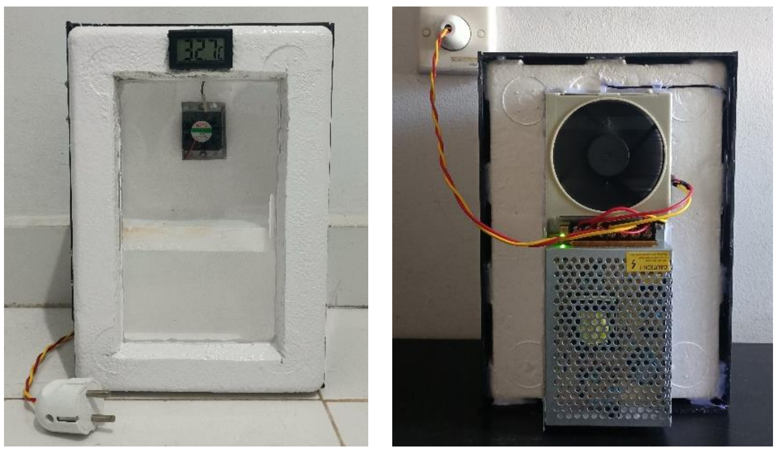


Figure 3. Results of Making a Portable Refrigerator Based on a Peltier Module

The thermoelectric cooling system operates by converting electrical energy into a temperature difference using the Peltier effect. When a direct current is applied to the Peltier module, heat is absorbed on one side (the cold side) and released on the opposite side (the hot side). The cold side is directed toward the interior of the cooling chamber, while the hot side is connected to an external heatsink equipped with a cooling fan to dissipate heat efficiently. This configuration allows the system to maintain a lower temperature inside the chamber while preventing heat accumulation on the external side of the module.

The prototype structure was constructed using a polystyrene box, which functions as a thermal insulator to minimize heat exchange with the surrounding environment. Polystyrene has a low thermal conductivity, making it suitable for maintaining cold temperatures within a confined space. Additionally, acrylic components were used to reinforce the structure and support the placement of electronic components.

To evaluate the performance of the developed cooling device, a series of experiments were conducted by placing water samples inside the cooling chamber. Two different water volumes were used in the experiments, namely 100 ml and 200 ml, to examine the effect of thermal load on cooling performance.

Table 1. Temperature change for 100 ml water

Time (minutes)	Initial Water Temp (°C)	Initial Chamber Temp (°C)	Water Temp After Cooling (°C)	Chamber Temp (°C)
10	30.8	35.4	29.9	29.4
20	30.8	35.4	29.1	28.6
30	30.8	35.4	28.4	28.2

From Table 1, the temperature of the 100 ml water sample decreased from 30.8°C to 28.4°C after 30 minutes of cooling. This represents a temperature reduction of 2.4°C, indicating that the thermoelectric cooling system is capable of lowering the temperature within a relatively short time for small volumes.

Table 2. Temperature change for 200 ml water

Time (minutes)	Initial Water Temp (°C)	Initial Chamber Temp (°C)	Water Temp After Cooling (°C)	Chamber Temp (°C)
10	30.8	35.4	30.3	30.0
20	30.8	35.4	29.8	29.6
30	30.8	35.4	29.4	29.3

Table 2 shows that when the water volume was increased to 200 ml, the cooling effect became less significant. The temperature decreased from 30.8°C to 29.4°C after 30 minutes, corresponding to a temperature drop of 1.4°C.

Discussion

The experimental results demonstrate that the portable refrigerator based on a Peltier module is capable of producing a measurable cooling effect, although its performance depends strongly on the thermal load inside the cooling chamber. The cooling process was more effective for the 100 ml water sample compared to the 200 ml sample, indicating that larger thermal masses require more energy to achieve the same temperature reduction. This behavior is consistent with fundamental heat transfer principles, where the amount of heat removed from a substance is proportional to its mass and specific heat capacity. Additionally, efficient heat dissipation through the heatsink and cooling fan is essential to maintain the temperature difference across the thermoelectric module.

4 Conclusion

This study successfully designed, constructed, and tested a portable refrigerator based on a thermoelectric Peltier module as an alternative environmentally friendly cooling technology. The developed system utilized a TEC-12706 Peltier module powered by a 12-volt DC power supply combined with heatsinks, cooling fans, and thermal insulation to produce a temperature difference inside a small cooling chamber. Experimental testing demonstrated that the device was capable of reducing the temperature of water samples placed inside the chamber. The experimental results showed that cooling performance was influenced by the thermal load placed in the system. For the 100 ml water sample, the temperature decreased from 30.8°C to 28.4°C within 30 minutes, resulting in a temperature drop of 2.4°C. Meanwhile, the 200 ml water sample experienced a smaller decrease, from 30.8°C to 29.4°C, corresponding to a 1.4°C temperature reduction during the same time period. These results indicate that smaller volumes are cooled more effectively because they contain less thermal energy that must be removed. From a physics perspective, the cooling process follows the principles of thermodynamics and heat transfer, where electrical energy is converted into heat transfer through the Peltier effect. Overall, the study demonstrates that portable thermoelectric refrigeration can serve as a compact, environmentally friendly cooling solution for small-scale applications.

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