INNOVATIVE JOURNAL
OF INTELLIGENT CONTROL AND OPTIMIZATION FOR ELECTRICAL SYSTEM

Vol. 3 (2026) No. 1

Publisher by AITEKS : Aliansi ahlI TEKnologi dan Sains
https://ijcioes.org/index.php/ijcioes

Performance Analysis of Peltier-Based Portable Refrigerator Using TEC1-12706 Module

Miftahul Fiqri [1] , Muhammad Fahreza [2 *] , Fadhel Putra Winarta [2] , Satrio Dwi Nugroho [2] , Roy Bayu Negara [2] , Fanji Azhari Arsal [2] , R. Reski Eka Putra [2] , Rizki Aditio Pribadi [2]

[1]Tanjung Balai Polytechnic, Jl. Sei raja, Tanjung Balai, 21331, Indonesia
[2] Department of Electrical Engineering, Padang State Polytechnic
Kampus Street, Limau Manis, Pauh, Padang, West Sumatra 25164, Indonesia
Corresponding author: mfahreza@pnp.ac.id

Abstract*— Conventional refrigeration systems commonly rely on refrigerants that may contribute to ozone depletion and global warming when leakage occurs. Consequently, environmentally friendly cooling technologies that eliminate the use of refrigerants have attracted increasing attention. This study presents the design, fabrication, and experimental evaluation of a portable refrigerator employing TEC1-12706 thermoelectric modules integrated with aluminum heatsinks and DC fans to enhance heat dissipation. The system was powered by a 12 V DC supply and evaluated under four operating conditions: a single module without load, a single module with a 600 mL bottled-water load, two modules without load, and two modules with load. Cooling performance was assessed by continuously monitoring chamber temperature, hot-side temperature, supply voltage, current, and power consumption throughout each experiment. Experimental results showed that the single-module configuration reduced the chamber temperature from 24.5°C to 17.2°C (7.3°C reduction) without load and from 25.0°C to 19.4°C (5.6°C reduction) with load. The dual-module configuration achieved greater cooling performance, reducing the chamber temperature from 30.5°C to 19.1°C (11.4°C reduction) without load and from 30.5°C to 21.5°C (9.0°C reduction) with load. These results demonstrate that increasing the number of thermoelectric modules enhances cooling capacity, whereas the presence of a thermal load decreases the attainable temperature reduction. Overall, the developed refrigerator provides an environmentally friendly, low-noise, and energy-efficient cooling solution without conventional refrigerants, making it suitable for portable refrigeration applications while highlighting the importance of effective thermal management and stable power supply for sustained performance.

***Keywords*— Portable refrigerator, thermoelectric cooler, peltier, TEC1-12706, environmentally friendly cooler.**

Manuscript received 1 Feb. 2026; revised 30 Apr. 2026; accepted 31 May. 2026. Date of publication 30 June. 2026.

I. INTRODUCTION

The increasing demand for food preservation, vaccine transportation, and beverage storage has accelerated the development of efficient and environmentally sustainable refrigeration technologies [1]. Refrigeration systems are indispensable in domestic, commercial, medical, and industrial applications because they maintain product quality, extend shelf life, and preserve temperature-sensitive materials [2]. However, most commercial refrigeration systems are based on vapor-compression technology, which relies on refrigerants with high global warming potential (GWP) and, in some cases, ozone depletion potential (ODP) [3]. Refrigerant leakage during operation or maintenance contributes to greenhouse gas emissions and environmental degradation [4]. Moreover, conventional compressor-based refrigerators generally require relatively high electrical power, generate noise and vibration, and are less suitable for portable applications or areas with limited access to electricity [5], [6]. Consequently, the development of compact, energy-efficient, and environmentally friendly refrigeration technologies has become an important research topic in recent years.

Among the promising alternatives, thermoelectric cooling (TEC) technology has attracted considerable attention because it operates without conventional refrigerants and contains no moving mechanical components [7], [8]. Thermoelectric cooling is based on the Peltier effect, in which a direct electric current passing through two dissimilar semiconductor materials produces a temperature difference between the hot and cold sides of the module [9]. Compared with vapor-compression systems, thermoelectric refrigerators offer several advantages, including compact size, simple construction, precise temperature control, low maintenance requirements, low noise and vibration, and the ability to operate directly from a DC power source, making them particularly suitable for portable refrigeration applications [10], [11], [12]. Nevertheless, the cooling performance of thermoelectric systems is strongly influenced by heat dissipation on the hot side. Inadequate thermal management increases the hot-side temperature, thereby reducing the temperature difference across the module and decreasing the overall coefficient of performance. Therefore, effective heatsink design, forced-air cooling, and appropriate thermal insulation are essential to maximize the cooling capability of thermoelectric refrigeration systems [13], [14].

Numerous studies have investigated the application of TEC1-12706 modules in portable refrigeration systems. Recent experimental studies demonstrated that thermoelectric cooling can be effectively applied in portable food coolers, vaccine carriers, blood transport boxes, and compact refrigeration systems because of its simple construction and environmental benefits [13]. However, the cooling performance varies considerably depending on operating conditions and system configuration. Previous studies have reported that the number of thermoelectric modules, input voltage, heatsink geometry, airflow rate, and thermal insulation are the primary factors influencing cooling efficiency and temperature reduction. In particular, increasing the number of TEC modules generally improves cooling capacity by enlarging the effective heat transfer area, whereas insufficient heat dissipation on the hot side significantly degrades system performance due to heat accumulation and reduced temperature difference across the modules [15] .

Several researchers have attempted to improve the performance of portable thermoelectric refrigerators through different approaches. Optimized the thermal management of thermoelectric cooling systems by improving heat transfer on the hot side, demonstrating that effective heatsink design substantially enhances cooling performance [16]. Similarly, Machfuroh and Huda investigated the influence of input voltage and operating time on the cooling performance of TEC1-12706 modules and reported that electrical operating conditions strongly affect the attainable temperature reduction [17]. Other studies have focused on portable cooling devices using single or multiple TEC modules, reporting that dual-module configurations generally produce lower cooling temperatures than single-module systems but require greater electrical power and more effective thermal management. These findings indicate that cooling performance is governed not only by the thermoelectric module itself but also by the interaction between electrical input, thermal management, module configuration, and cooling load [18] .

Although previous studies have demonstrated the feasibility of thermoelectric refrigeration using TEC1-12706 modules, several limitations remain. Most published works evaluated either a single-module or a dual-module configuration under only one operating condition, while the combined influence of module quantity and thermal load has received limited attention. Moreover, previous investigations primarily emphasized prototype development or temperature reduction without providing a comprehensive comparison of cooling performance under different operating scenarios [19], [20]. Consequently, the respective contributions of thermoelectric module configuration and thermal load to the overall cooling performance of portable refrigerators remain insufficiently understood. Addressing these issues is essential for optimizing thermoelectric refrigeration systems intended for portable applications, where cooling performance, energy consumption, and battery endurance must be simultaneously considered .

To address these research gaps, this study develops and experimentally evaluates a portable refrigerator employing both single and dual TEC1-12706 module configurations under no-load and load conditions using a 600 mL bottled-water thermal load. Unlike previous studies, the proposed experimental approach provides a systematic comparison of four operating conditions to quantify the influence of module quantity and thermal load on chamber temperature reduction. In addition, electrical characteristics, including supply voltage, operating current, and power consumption, are continuously monitored to evaluate their relationship with cooling performance. The findings of this study provide practical insights into the design of portable thermoelectric refrigeration systems by identifying the trade-off between cooling capability and electrical power demand, thereby supporting the development of more efficient, environmentally friendly, and sustainable portable cooling technologies..

II. METHOD

A functional block diagram was developed to describe the operating principle of the proposed portable refrigerator. This diagram illustrates the flow of electrical power and the interaction among the major system components, thereby facilitating a better understanding of the system operation.

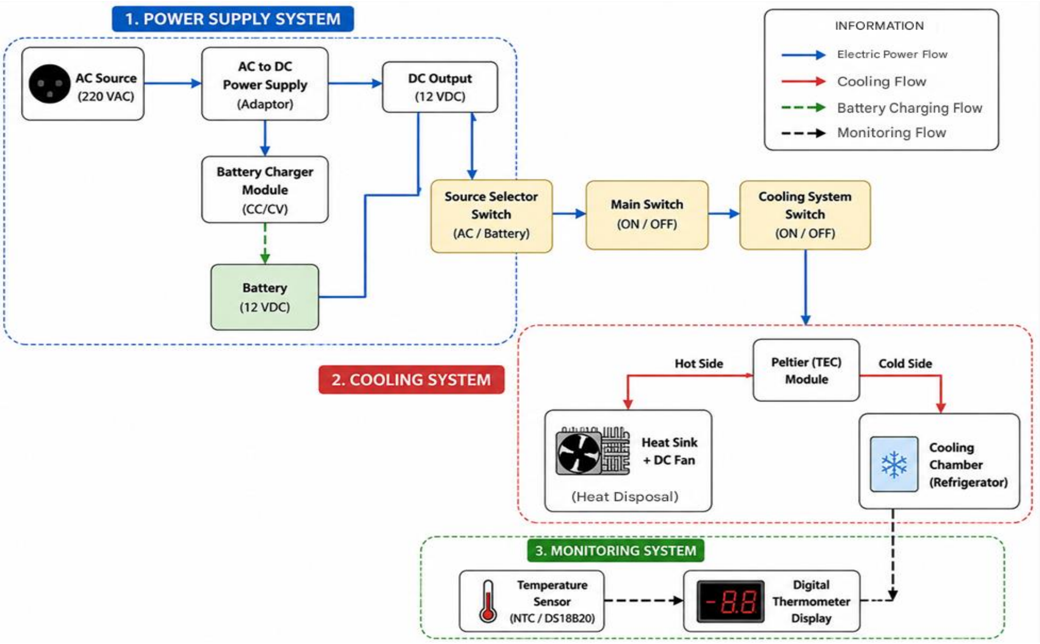

Figure 1. Block Diagram of Portable Refrigerator Design Using *Peltier System*

a. Peltier block is the main source tool in a refrigerator, it functions to produce cold temperatures and hot temperatures are used to cool the inside of the refrigerator.
b. The battery block functions to store electrical energy sources generated from PLN sources.
c. on / off switch block functions to turn the refrigerator on or off when needed to save battery consumption and make it last longer.
d. The power supply block functions to convert DC current into AC current.
e. The Heatsink Block functions to transfer the hot and cold temperatures produced by the Peltier so that the temperature is evenly distributed by the DC fan.
f. The DC fan functions to blow out cold and hot air produced by the Peltier.
g. The digital thermometer block functions to measure the cold temperature in the refrigerator.
h. The AC source block is when the battery supplies power and also powers the existing components

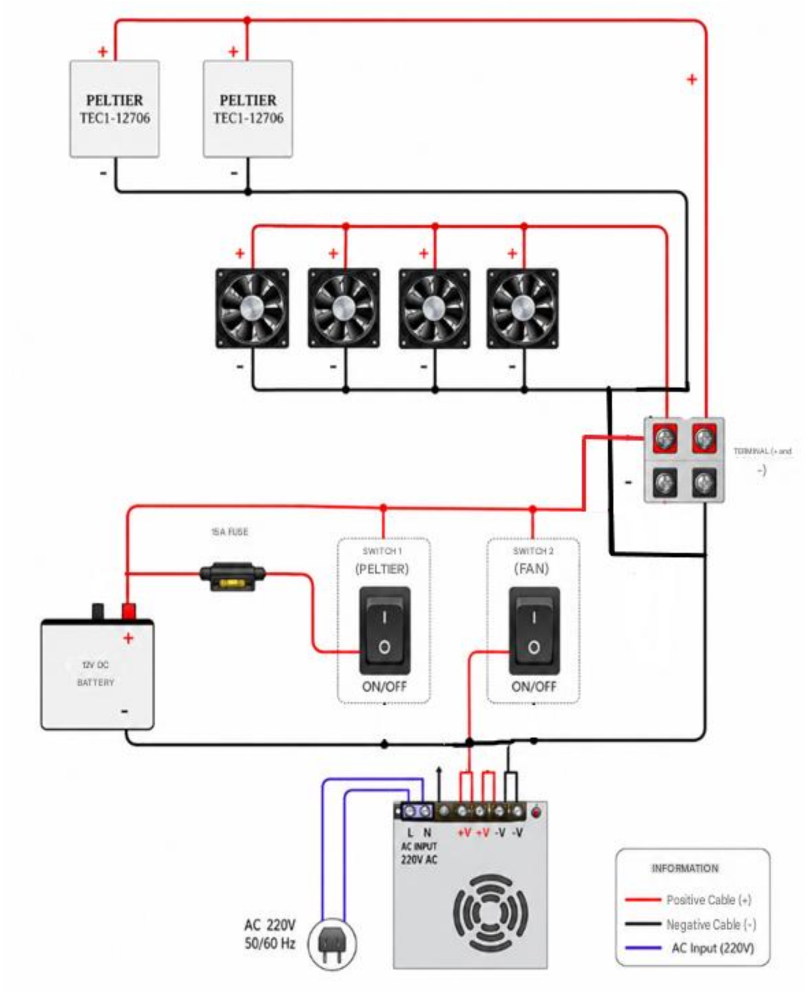

Figure 2. Refrigerator circuit

Figure 2 illustrates the electrical configuration and operating principle of the proposed portable refrigerator. During operation, electrical power is supplied either by a 12 V DC battery or an external power supply. When the ON/OFF switches are activated, electrical current flows to the TEC1-12706 thermoelectric modules and the auxiliary components, including the DC fans and digital thermometer. The supplied direct current induces the Peltier effect, generating a temperature difference across the thermoelectric modules. Consequently, the cold side absorbs heat from the cooling chamber, while the hot side transfers heat to the surrounding environment.

To maintain efficient heat transfer, the hot side of each thermoelectric module is attached to an aluminum heatsink equipped with a DC fan that enhances heat dissipation through forced convection. Meanwhile, the cold side is connected to a coldsink positioned inside the cooling chamber. An additional DC fan circulates the cooled air throughout the chamber, resulting in a more uniform temperature distribution and improving the cooling performance for food and beverage storage.

The proposed system is powered by a 12 V, 7 Ah rechargeable battery to enable portable operation. A dual-switch electrical configuration was implemented to ensure safe and flexible operation when switching between battery and external power sources. The first switch controls the main power supplied to the refrigeration system, while the second switch is used to select the operating mode. This configuration prevents the thermoelectric modules and auxiliary components from operating during battery charging, thereby improving operational safety and protecting the electrical components from unintended operation

III. RESULTS AND DISCUSSION

First Experimental Data for the Portable Refrigerator Design Using a Peltier System

The portable refrigerator consists of several main components, including a TEC1-12706 Peltier module, a heatsink, a coldsink, DC fans, and a digital thermometer. The heatsink is installed on the hot side of the Peltier module to dissipate heat to the surrounding environment, while the coldsink is mounted on the cold side to distribute the cooling effect inside the refrigerator chamber. A DC fan is attached to the heatsink to enhance heat dissipation, whereas another fan is installed near the coldsink to circulate cold air uniformly throughout the cooling chamber. The heatsink assembly is positioned outside the refrigerator, while the coldsink is located inside the cooling chamber.

The system operates using a 12–13 V DC power supply, which can be provided either by a 12 V/7 Ah rechargeable battery or an external power supply. Experimental tests were conducted using one or two Peltier modules under both no-load and load conditions, where the load consisted of two 280 mL bottles of mineral water. Temperature measurements were performed using a digital thermometer installed inside the cooling chamber and on the heatsink to monitor the cold-side and hot-side temperatures, respectively. The experimental results obtained from the first test are presented in Table 1.

Table I.
Results of the First Refrigerator Experiment

No	Time (Minute)	Temperature (°C) Cold	Temperature (°C) Hot	Voltage (V)	Current (A)	Power (W)
1	0	24.5	25	12.49	2.84	35.47
2	5	20.9	28.5	12.06	2.82	34.25
3	10	19,3	27.9	11,98	2,80	33,54
4	15	18,4	27,5	11,88	2,79	33,14
5	20	17,9	27,5	11,79	2,77	32,40
6	25	17,5	17,9	11,70	2,75	32,17
7	30	17,3	27,9	11,61	2,73	31,92
8	35	17,3	27,9	11,50	2,69	30,93
9	40	17,2	28,1	11,38	2,66	30,27
10	45	17,2	27,9	11,24	2,23	25,06
11	50	17,2	27,7	11,07	2,59	28,67
12	55	17,3	27,6	10,81	2,52	27,24
13	60	17,4	27,6	10,35	2,41	24,94
14	65	17,5	27,6	10,08	2,34	23,58

Based on the experimental results presented in Table 1, the portable refrigerator exhibited satisfactory cooling performance during 65 minutes of operation. The cold-side temperature decreased from an initial value of 24.5°C to 17.2°C after 40 minutes, corresponding to a maximum temperature reduction of 7.3°C. The temperature remained relatively stable between 17.2°C and 17.5°C until the end of the experiment, indicating that the cooling system had reached a steady-state condition where the cooling capacity of the Peltier module was balanced by the heat entering the cooling chamber from the surrounding environment.

The hot-side temperature increased from 25.0°C to 28.5°C during the first 5 minutes and then remained relatively stable within the range of 27.5–28.1°C throughout the test, demonstrating the effectiveness of the heatsink and fan in dissipating heat. During the same period, the supply voltage gradually decreased from 12.49 V to 10.08 V, accompanied by a reduction in current from 2.84 A to 2.34 A, resulting in a decrease in electrical power from 35.47 W to 23.58 W. Despite the reduction in electrical input, the cooling chamber temperature remained nearly constant after reaching its minimum value, indicating that the proposed thermoelectric refrigeration system maintained stable cooling performance throughout the experimental period.

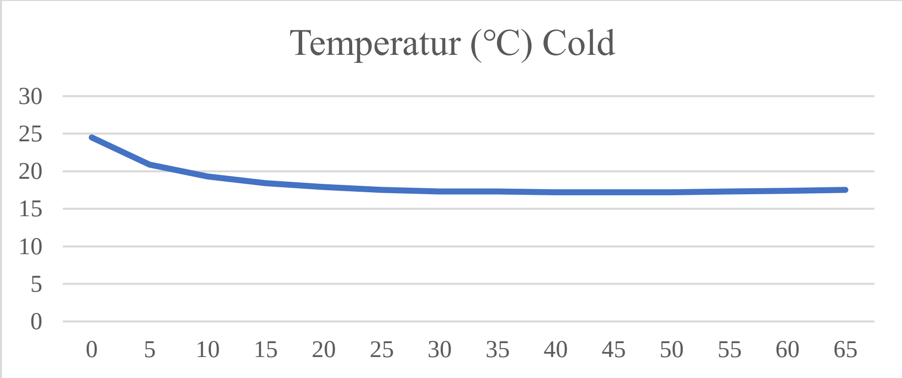

Figure 3 . Graph of the First Experimental Test

Based on Figure 3, the cooling chamber temperature decreased rapidly during the first 20 minutes of operation, dropping from 24.5°C to 17.9°C, which indicates the highest cooling rate during the experiment. Afterward, the rate of temperature reduction gradually declined until the minimum temperature of 17.2°C was reached at the 40th minute. This behavior indicates that the cooling capacity of the Peltier module gradually approached the rate of heat gain from the surrounding environment, leading the system toward thermal equilibrium.

From the 40th to the 65th minute, the cooling chamber temperature remained relatively stable within the range of 17.2–17.5°C, indicating that the system had reached a steady-state condition. During the same period, the supply voltage gradually decreased from 12.49 V to 10.08 V, accompanied by a reduction in the operating current to 2.34 A, resulting in lower electrical power supplied to the Peltier module. Despite this reduction in electrical input, the cooling chamber temperature remained nearly constant, demonstrating that the combined performance of the Peltier module, heatsink, coldsink, and forced-air cooling system was sufficient to maintain stable cooling throughout the experimental period.

Experimental Results of the Portable Refrigerator Using a Single TEC1-12706 Module

The second experiment was conducted using the same portable refrigerator configuration as the first test. However, unlike the previous experiment, the refrigerator was tested under load conditions using a 600 mL bottle of mineral water. The corresponding experimental results are presented in Table 2

Table II.
Temperature Measurements with One TEC1-12706 Module Under Load Conditions

No	Time (Minute)	Temperature (°C) Cold	Temperature (°C) Hot	Voltage (V)	Current (A)	Power (W)
1	0	25	25.5	12.49	3.13	39.09
2	5	21.8	27	12.12	2.91	35.26
3	10	20.7	27	12.05	2.89	34.82
4	15	20.3	27.2	11.98	2,87	34,38
5	20	20,1	26,8	11,90	2.85	33,91
6	25	19,9	27,1	11,83	2.84	33,59
7	30	19.8	27,1	11,76	2,82	33,16
8	35	19,6	27	11,67	2,80	32,67
9	40	19,5	27,2	11,57	2,77	32,04
10	45	19,4	26,9	11,47	2,75	31,54
11	50	19,4	27	11,36	2,72	30,89
12	55	19,4	26,8	11,21	2,67	29,93
13	60	19,4	26,9	11,09	2,63	29,16

Based on the experimental results presented in Table 2, the portable refrigerator exhibited satisfactory cooling performance under load conditions during 60 minutes of operation. The cold-side temperature gradually decreased from an initial value of 25.0°C to 19.4°C at the 45th minute and remained stable until the end of the experiment, corresponding to a total temperature reduction of 5.6°C. This result demonstrates that the proposed thermoelectric refrigeration system effectively absorbed heat from the cooling chamber despite the presence of a thermal load. Meanwhile, the hot-side temperature increased from 25.5°C to approximately 27.0°C during the initial stage of operation and subsequently remained relatively stable within the range of 26.8–27.2°C. The small temperature fluctuation indicates that the heatsink and fan assembly effectively dissipated the heat generated by the thermoelectric module throughout the cooling process.

The electrical characteristics also changed gradually during the experiment. The supply voltage decreased from 12.49 V to 11.09 V, while the operating current decreased from 3.13 A to 2.63 A, resulting in a reduction in electrical power from 39.09 W to 29.16 W. Despite the decrease in electrical input, the cooling chamber temperature remained stable at 19.4°C after reaching its minimum value. These findings demonstrate that the proposed portable refrigerator maintained stable cooling performance under load conditions, indicating that the thermoelectric cooling system remained effective even as the available battery power gradually decreased during operation.

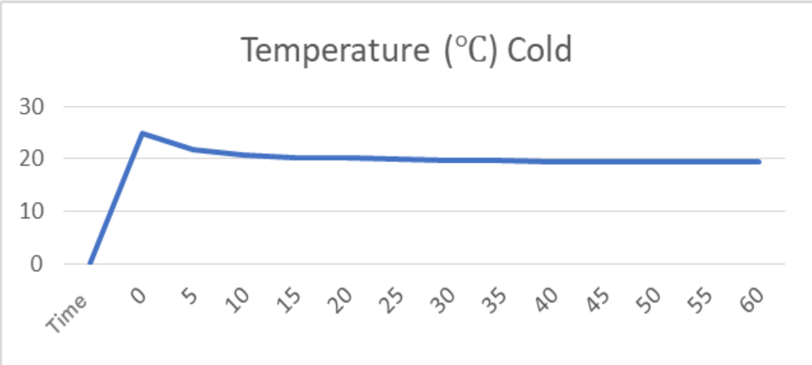

Figure 4 . Graph of the Second Experimental Test

Based on Figure 4, the cooling chamber temperature gradually decreased throughout the experiment, reaching a minimum value of 19.4°C at the 45th minute and remaining stable until the end of the 60-minute test. The average cooling chamber temperature recorded during the experiment was 20.2°C. The stable temperature observed after 45 minutes indicates that the system had reached a steady-state condition, where the cooling capacity of the Peltier module was balanced by the heat gained from the surrounding environment and the thermal load inside the cooling chamber.

During the same period, the battery voltage gradually decreased from 12.49 V to 11.09 V, with an average operating current of approximately 2.8 A. This reduction in voltage resulted in a corresponding decrease in the electrical power supplied to the thermoelectric module. Nevertheless, the cooling chamber temperature remained below 20°C throughout the steady-state period, demonstrating that the TEC1-12706-based portable refrigerator maintained stable and effective cooling performance under load conditions despite the gradual reduction in battery power.

Experimental Results of the Portable Refrigerator Using Two TEC1-12706 Modules

The third experiment was conducted using the same portable refrigerator configuration as the previous test, with the addition of a second TEC1-12706 module installed at the rear of the refrigerator to enhance the cooling capacity. The refrigerator was tested under no-load conditions, and the prototype was covered with a protective sticker as part of the final assembly. The corresponding experimental results are presented in Table 3.

Table III.
Experimental Results of the Portable Refrigerator with Two TEC1-12706 Modules Under No-Load Conditions

No	Time (Minute)	Temperature (°C) Cold	Temperature (°C) Hot	Voltage (V)
1	0	30.5	31.8	12.21
2	5	24.7	38.5	12.00
3	10	21.8	35.2	11.79
4	15	20.3	35.3	11.62
5	20	19,4	35,2	11,42
6	25	19,2	37,3	11,17
7	30	19.1	36,8	10,73
8	35	20,4	35,4	7,85

Based on the experimental results presented in Table 3, the portable refrigerator equipped with two TEC1-12706 thermoelectric modules demonstrated improved cooling performance under no-load conditions. The cold-side temperature gradually decreased from an initial value of 30.5°C to a minimum of 19.1°C after 30 minutes of operation, corresponding to a total temperature reduction of 11.4°C. After reaching the minimum temperature, the cold-side temperature increased slightly to 20.4°C at the 35th minute. Meanwhile, the hot-side temperature increased from 31.8°C to 38.5°C during the first 5 minutes and subsequently fluctuated within the range of 35.2–37.3°C. These results indicate that the thermoelectric modules effectively transferred heat from the cooling chamber to the hot side, while the heatsink and fan assembly maintained stable heat dissipation throughout the cooling process.

During the experiment, the supply voltage gradually decreased from 12.21 V at the beginning of the test to 10.73 V after 30 minutes, followed by a significant drop to 7.85 V at the 35th minute. This reduction in voltage was accompanied by a slight increase in the cold-side temperature from 19.1°C to 20.4°C, indicating a reduction in the cooling capacity as the available electrical power decreased. Nevertheless, the cooling chamber temperature remained below 21°C throughout the experiment, demonstrating that the proposed dual-TEC refrigeration system maintained effective cooling performance despite the decline in battery voltage. These findings also suggest that maintaining a stable power supply is essential for achieving consistent cooling performance in portable thermoelectric refrigeration systems.

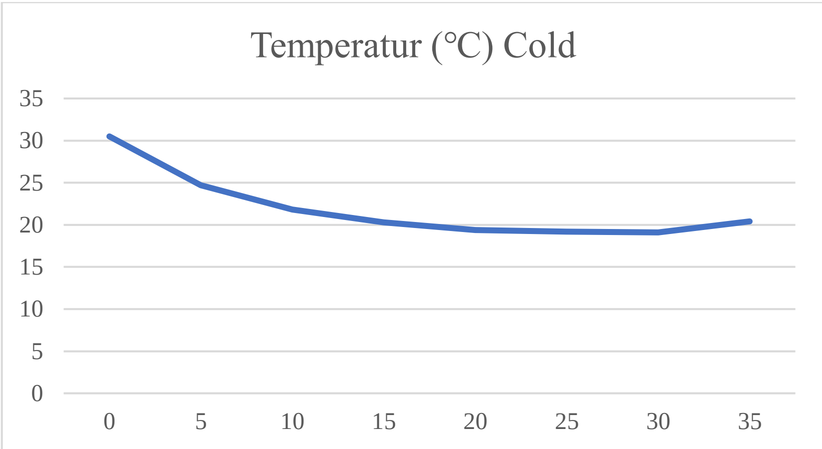

Figure 5. Graph of the Third Experimental Test

Based on Figure 5, the portable refrigerator equipped with two TEC1-12706 modules exhibited a faster cooling rate than the single-module configuration. The cooling chamber temperature decreased rapidly from 30.5°C to 24.7°C within the first 5 minutes and continued to decline until reaching a minimum value of 19.1°C at the 30th minute. Subsequently, the temperature increased slightly to 20.4°C at the 35th minute, corresponding to the significant reduction in battery voltage, which lowered the cooling capacity of the thermoelectric modules. Throughout the 35-minute experiment, the average cooling chamber temperature was 22.3°C.

The rapid temperature reduction observed during the initial stage of operation demonstrates that the addition of a second TEC1-12706 module significantly enhanced the cooling capacity of the proposed refrigeration system. However, the improved cooling performance was accompanied by higher electrical power consumption, resulting in a faster decline in battery voltage and a corresponding reduction in cooling performance toward the end of the experiment. Overall, the results indicate that the dual-module configuration provides superior cooling performance compared with the single-module system. Nevertheless, this configuration requires a higher-capacity battery or a more stable DC power supply to sustain effective cooling performance during extended operation.

Test Data Fourth Design Refrigerator Portable Using Two Peltier Systems

The fourth experiment was performed using the same portable refrigerator configuration as the previous test, with the addition of a second TEC1-12706 thermoelectric module installed at the rear of the refrigerator. The system was evaluated under load conditions using a 600 mL bottle of mineral water placed inside the cooling chamber. The experimental results obtained under these operating conditions are presented in Table 4.

Table IV.

Temperature Measurements of the Portable Refrigerator Using Two TEC1-12706 Modules Under Load Conditions

No	Time (Minute)	Temperature (°C) Cold	Temperature (°C) Hot	Voltage (V)
1	0	30.5	31.8	12.22
2	5	26	37.8	12.10
3	10	24	37.9	11.96
4	15	23.1	37.9	11.81
5	20	22.3	37.7	11,64
6	25	22,3	37,6	11,43
7	30	21,9	37,3	11,17
8	35	21,6	37,3	10,69
9	40	21,5	36,4	8,26

Based on the experimental results presented in Table 4, the portable refrigerator equipped with two TEC1-12706 thermoelectric modules exhibited effective cooling performance under load conditions during the 40-minute test. The cold-side temperature gradually decreased from an initial value of 30.5°C to 21.5°C, corresponding to a total temperature reduction of 9.0°C. The cooling rate was highest during the initial stage of operation and gradually decreased after the 15th minute before approaching a stable condition toward the end of the experiment. Meanwhile, the hot-side temperature increased from 31.8°C to 37.8°C within the first 5 minutes and reached a maximum value of 37.9°C between the 10th and 15th minutes. Thereafter, it gradually decreased to 36.4°C at the end of the test, indicating that the heatsink and fan assembly effectively dissipated the heat generated by the thermoelectric modules.

The electrical characteristics also changed during the experiment. The supply voltage gradually decreased from 12.22 V to 11.17 V after 30 minutes and further declined to 8.26 V at the end of the test. This reduction in voltage decreased the electrical power supplied to the thermoelectric modules, resulting in a lower cooling rate during the final stage of operation. Nevertheless, the cooling chamber temperature remained within the range of 21–22°C until the completion of the experiment. These results demonstrate that the dual-TEC configuration maintained effective cooling performance under load conditions, although the overall system performance remained dependent on the stability of the power supply voltage.

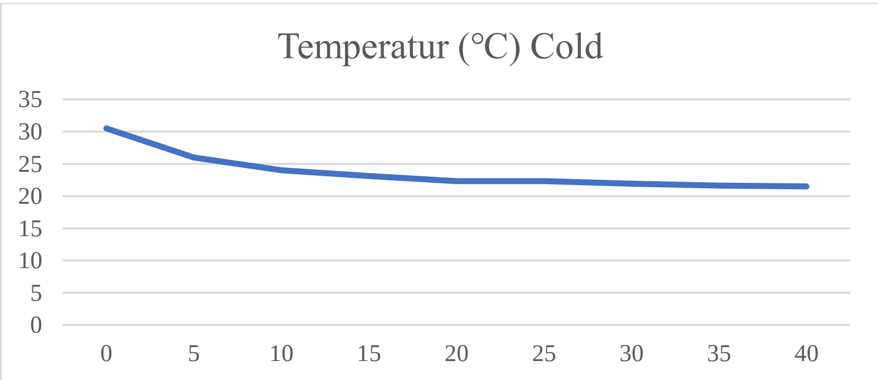

Figure 6 . Graph of the Fourth Experimental Test

Based on Figure 6, the cooling chamber temperature gradually decreased from 30.5°C to 21.5°C during the 40-minute experiment. The highest cooling rate occurred within the first 15 minutes of operation, after which the rate of temperature reduction gradually declined until the system reached a relatively stable temperature range of 21.5–22.3°C. The average cooling chamber temperature recorded during the experiment was 23.6°C, indicating that the proposed system maintained effective cooling performance under load conditions.

Compared with the no-load test using two TEC1-12706 modules, the final cooling chamber temperature under load conditions was slightly higher because part of the cooling capacity was utilized to remove heat from the thermal load rather than solely reducing the air temperature inside the chamber. Nevertheless, the system successfully reduced the load temperature from 29.1°C to 21.6°C, demonstrating effective heat transfer from the load to the thermoelectric modules. During the experiment, the battery voltage gradually decreased from 12.22 V to 8.26 V, reducing the electrical power supplied to the thermoelectric modules and consequently lowering the cooling rate during the final stage of operation. Despite this reduction in electrical input, the cooling chamber temperature remained within the range of 21–22°C, demonstrating that the dual-TEC configuration maintained stable cooling performance under load conditions. Overall, these results confirm that the use of two TEC1-12706 modules provides higher cooling capacity than the single-module configuration. However, the improved cooling performance is accompanied by increased electrical power consumption, indicating that a higher-capacity battery or a more stable DC power supply is required to sustain efficient operation over extended periods..

IV. CONCLUSION

This study successfully designed and experimentally evaluated a portable refrigerator based on TEC1-12706 thermoelectric modules under four operating conditions. The single-module configuration reduced the chamber temperature from 24.5°C to 17.2°C (7.3°C reduction) under no-load conditions and from 25.0°C to 19.4°C (5.6°C reduction) under load conditions. Meanwhile, the dual-module configuration achieved greater cooling performance by reducing the chamber temperature from 30.5°C to 19.1°C (11.4°C reduction) without load and from 30.5°C to 21.5°C (9.0°C reduction) with load. These results confirm that increasing the number of thermoelectric modules improves cooling capacity, whereas the presence of a thermal load reduces the achievable cooling performance. Overall, the proposed thermoelectric refrigerator provides an environmentally friendly and low-noise cooling solution without refrigerants; however, the higher power demand of the dual-module configuration highlights the need for improved thermal management and a more stable power supply to enhance long-term performance.

REFERENCES

[1] M. A. Alrefae, “Enhanced Performance of a Thermoelectric Module with Heat Pipes for Refrigeration Applications,” Energies, vol. 18, no. 10, Art. no. 2426, May 2025, doi: 10.3390/en18102426.

[2] C. Kypraiou and T. Varzakas, “Evolution and Evaluation of Ultra-Low Temperature Freezers: A Comprehensive Literature Review,” Foods, vol. 14, no. 13, Art. no. 2298, 2025, doi: 10.3390/foods14132298.

[3] Mark O. McLinden et al. ,New refrigerants and system configurations for vapor-compression refrigeration.Science370,791-796(2020).DOI:10.1126/science.abe3692.

[4] V. W. Bhatkar, V. M. Kriplani, and G. K. Awari, “Alternative refrigerants in vapour compression refrigeration cycle for sustainable environment: A review of recent research,” International Journal of Environmental Science and Technology, vol. 10, no. 4, pp. 871–880, Jul. 2013, doi: 10.1007/s13762-013-0202-7

[5] R. Kumar and A. Agrawal, “A Comprehensive Study on a Household Refrigerator with a PCM-Enhanced Condenser: Experimental and Numerical Approaches: A Review,” International Journal for Research in Applied Science and Engineering Technology, vol. 11, no. 10, pp. 191–198, Oct. 2023, doi: 10.22214/ijraset.2023.55964.

[6] M. Bozorgi, P. Roy, A. R. M. Siddique, K. Venkateshwar, S. Tasnim, and S. Mahmud, “Experimental investigation and life cycle assessment of a phase change material (PCM) based thermoelectric (TE) refrigerator,” International Journal of Thermofluids, vol. 19, Art. no. 100394, Aug. 2023, doi: 10.1016/j.ijft.2023.100394..

[7] T. Machfuroh and M. A. N. Huda, "Analysis of the Effect of Input Voltage Variation and Time on the Cooling Performance of 1-12706 Type Portable Thermoelectric Cooler System," Evrimata: Journal of Mechanical Engineering, 2026

[8] R. K. Jain, R. Singh, and A. Kumar, “Materials, Models, and Applications of Thermoelectric Cooling,” International Journal of Research in Commerce, IT, Engineering and Social Sciences, vol. 11, no. 10, pp. 335–342, 2021, doi: 10.5958/2249-7137.2021.02095.4

[9] W.-Y. Chen, X.-L. Shi, J. Zou, and Z.-G. Chen, “Thermoelectric Coolers: Progress, Challenges, and Opportunities,” Small Methods, vol. 6, no. 2, Art. no. 2101235, Feb. 2022, doi: 10.1002/smtd.202101235

[10] A. Kumar, N. Yadav, V. Pandey, and T. P. Bhogal, “A Research Paper on Air Cooling Using Peltier Effect,” PARIPEX – Indian Journal of Research, vol. 10, no. 9, Sep. 2021, doi: 10.36106/paripex/9206532

[11] R. P. Patil, P. Suryawanshi, A. Pawar, and A. Pawar, “Thermoelectric Refrigeration Using Peltier Effect,” International Journal of Engineering Sciences & Research Technology, vol. 6, no. 5, pp. 677–682, May 2017, doi: 10.5281/zenodo.800636

[12] T. Guclu, P. M. Cuce, E. Cuce, E. Alvur, and H. Sen, “TEC-Driven Mini Refrigerators: Recent Applications With Performance Characteristics,” Journal of Electronic Materials, vol. 53, no. 11, pp. 6630–6654, Nov. 2024, doi: 10.1007/s11664-024-11435-3

[13] M. K. Shilpa, M. A. Raheman, A. Aabid, M. Baig, R. K. Veeresha, and N. Kudva, “A Systematic Review of Thermoelectric Peltier Devices: Applications and Limitations,” Micromachines, vol. 16, no. 2, Art. no. 214, Feb. 2025, doi: 10.3390/mi16020214

[14] A. C. Sulaiman, N. A. M. Amin, M. H. Basha, M. S. A. Majid, N. F. M. Nasir, and I. Zaman, “Cooling Performance of Thermoelectric Cooling (TEC) and Applications: A Review,” Journal of Advanced Research in Applied Mechanics, vol. 124, no. 1, pp. 32–51, 2025, doi: 10.37934/aram.124.1.3251

[15] A. Liu, H. Xie, Z. Wu, and Y. Wang, “Advances and Outlook of TE-PCM System: A Review,” Carbon Neutrality, vol. 1, Art. no. 20, 2022, doi: 10.1007/s43979-022-00018-4

[16] D. Enescu, “Thermoelectric Energy Harvesting: Basic Principles and Applications,” in Green Energy Advances. London, U.K.: IntechOpen, 2019, doi: 10.5772/intechopen.83495

[17] T. Machfuroh and M. A. N. Huda, “Analysis of the Effect of Input Voltage Variation and Time on the Cooling Performance of 1-12706 Type Portable Thermoelectric Cooler System,” Evrimata: Journal of Mechanical Engineering, vol. 2, no. 4, Dec. 2025, doi: 10.70822/evrmata.vi.118.

[18] H. Zhu, W. Li, A. Nozariasbmarz, N. Liu, Y. Zhang, S. Priya, and B. Poudel, “Half-Heusler Alloys as Emerging High Power Density Thermoelectric Cooling Materials,” Nature Communications, vol. 14, no. 1, Art. no. 3300, Jun. 2023, doi: 10.1038/s41467-023-38446-0.

[19] P. Aranguren, Ed., Bringing Thermoelectricity into Reality. London, U.K.: IntechOpen, 2018, doi: 10.5772/intechopen.68717.

[20] Y. Hu, B. Shen, K. R. Gluesenkamp, and S. F. Y. Motta, “Experimental Investigation on Cooling Performance of a Thermoelectric Freezer,” in Proc. 20th Int. Refrigeration and Air Conditioning Conf. at Purdue, West Lafayette, IN, USA, Jul. 2024, Paper 2265

.