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Thermoelectric Generator Performance as a Power Generator in a Portable Stove

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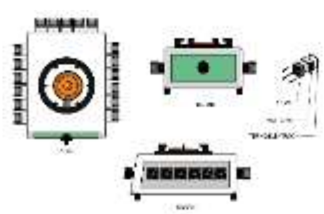
Graphical Abstract



Abstract
This study analyzes the performance of a non-branded thermoelectric generator (TEG) installed on a portable stove and evaluates its potential as a low-cost micro power source. The experiment was conducted by varying the temperature difference (ΔT) between the hot and cold sides of the TEG, followed by measuring the resulting current, voltage, power output, and conversion efficiency at 5-minute intervals. The maximum current produced was **0.0526 A**, with peak output power of **0.105 W** and maximum efficiency of **0.37%** at the optimum ΔT. The methodology involved repeated measurements, calibrated thermocouples, controlled heat input, and forced-air cooling. Compared to findings in previous studies, the power and efficiency values remain lower due to material limitations of the low-cost module and suboptimal heat transfer configuration. The novelty of this research lies in the performance characterization of non-branded TEG modules on portable stoves under real heating conditions, which is rarely discussed in prior studies. These results demonstrate that although efficiency is low, TEGs can serve as supplementary power sources for micro-devices in off-grid environments.

Keywords: Thermoelectric generator, Seebeck effect, portable stove, renewable energy, energy conversion.

1. INTRODUCTION

The global energy crisis due to dwindling fossil fuel reserves and increasing energy demand in remote areas has driven the development of innovative renewable energy technologies [1]. One potential solution is utilizing waste heat from household appliances such as portable stoves using thermoelectric generators (TEGs). TEGs are devices capable of converting temperature differences into electrical energy through the Seebeck effect [2]. This technology has great potential to provide emergency power sources, especially in areas difficult to reach by conventional electricity grids. With the increasing need for sustainable energy, the development of TEG-based portable stoves is a strategic effort to realize environmentally friendly and applicable technology in various field conditions [3].

In recent decades, various studies have demonstrated that TEG technology has significant potential to utilize waste heat to generate electrical energy [4]. For example, research by Kim et al. (2020) showed that the use of TEGs in household heating systems can generate sufficient electrical power for the needs of small electronic devices [5]. Furthermore, previous research has also discussed optimizing TEG efficiency by selecting thermoelectric materials with low thermal conductivity and high power factor characteristics [6].

TEG technology also offers advantages in terms of reliability, no moving parts, and minimal maintenance, making it an ideal solution for applications in extreme environments or remote areas [7]. Portable TEG-based stoves can be a multifunctional solution, not only as a cooking tool but also as a backup power source in emergency situations. Therefore, this study aims to develop and evaluate the performance of TEGs as power generators in portable stoves, which are expected to contribute to the development of renewable energy in the future [8].

The development of small-scale energy generation, one of which is the application of new and renewable energy (NRE), in the context of thermoelectric generators (TEGs), shows significant potential to improve energy efficiency and reduce dependence on fossil fuels. Thermoelectric technology offers an attractive solution because it can utilize waste heat from various industrial processes and vehicles to generate electricity. Non-branded thermoelectric modules are an economical option compared to commercial products, but information on their performance is still limited. This research is expected to contribute to the development of thermoelectric technology and its utilization in various sectors.

TEGs function by converting temperature differences into electrical energy, utilizing the Seebeck phenomenon, and can be used in a variety of applications, including recovering lost heat energy and providing electricity in remote areas (Fahet, 2023; Diki et al., 2022). In the Indonesian context, where fossil-based energy availability is decreasing, the application of TEGs as an alternative solution is becoming increasingly relevant.

The increasing global demand for energy and the declining availability of fossil fuel reserves have encouraged the development of small-scale renewable technologies. One promising technology for waste-heat recovery is the thermoelectric generator (TEG), which converts heat directly into electricity via the Seebeck effect. While numerous studies have explored TEG applications in automotive exhausts, industrial waste heat, or building heating systems, the performance of low-cost and non-branded TEG modules applied to compact heating systems such as portable stoves remains insufficiently documented.

Previous studies generally used commercial modules with known specifications and higher figures of merit (ZT). Their reported efficiencies typically range from 1–5% under moderate ΔT conditions. However, in many developing countries—including Indonesia—portable stoves are widely used in rural and outdoor settings, and the adoption of low-cost TEG modules could provide emergency power for sensors, radios, or low-power lighting. Despite this potential, three research gaps remain:

1. Limited analysis of the electrical performance of non-branded TEG modules under real stove heating conditions.
2. Lack of discussion on the effects of forced cooling and thermal contact quality on ΔT stability in portable systems.
3. Scarce performance comparisons between experimental results and theoretical predictions for low-cost modules.

To address these gaps, this study aims to (1) evaluate the current, heat absorption, electrical power, and efficiency of TEG modules on a portable stove; (2) analyze the influence of ΔT on electrical performance based on theory; and (3) identify limitations and potential design improvements for future applications.

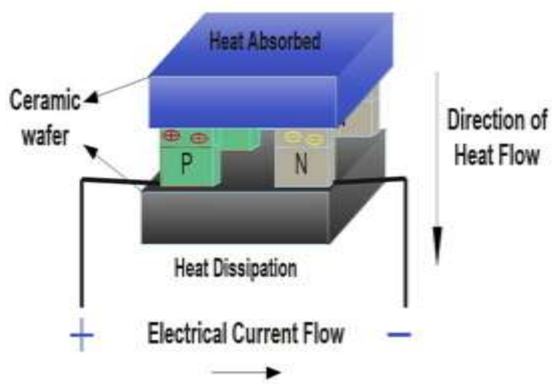


Figure 1: Thermoelectric Generator Mechanism

2. METHOD

This section systematically explains the stages and approaches used in conducting the research. The research method was designed to obtain accurate and reliable data for evaluating the performance of a thermoelectric generator (TEG) applied to a portable stove. The description includes the experimental design, equipment and material specifications, testing procedures, and data analysis methods. With this approach, it is hoped that the research results will provide a comprehensive overview of the effectiveness of converting heat energy into electrical energy and its potential for portable use.

a. Research Time and Location

The research is planned for approximately 7 months, from April 2025 to November 2025, at one of the Mechanical Engineering Education laboratories of the Faculty of Engineering, Makassar State University, located on Jalan Daeng Tata Raya Parang Tambung, Mannuruki, Tamalate District, Makassar City, South Sulawesi 90224.

b. Research Tools and Materials

The tools and materials used in this research are as follows:
1. Portable Stove
2. Display and Thermocouple
3. Digital Multimeter
4. Power Supply
5. Fan
6. Heatsink
7. Thermal Paste
8. Matrax Cork

c. TEG Installation on the Stand
1. Calculating the resistance of a non-branded thermoelectric module using a multimeter.
2. Installing the TEG on the stove body, which has been coated with thermal paste and its cables coated with aluminum.
3. Installing the thermocouple, mat, heatsink, and fan on the stove body stand.
4. Installing the TEG stand on the portable stove body.
5. Connect the thermocouple cable to the temperature reading display.
6. Connect the red and black TEG leads to the multimeter display to measure the resulting voltage.

d. Testing Method
1. The power supply, blower, cooling fan, temperature display, and multimeter are set to the on position.
2. The portable stove is turned on.
3. The temperature and voltage generated are recorded every 5 minutes for 60 minutes, and then for another 30 minutes, the temperature and residual voltage generated by the portable stove flame are recorded until the stove wall temperature equals the ambient temperature. The above procedure is repeated for each module variation.

e. Schematic design of the test installation and measurement system

The schematic design of the measurement points on the thermoelectric generator is shown in Figure 2.

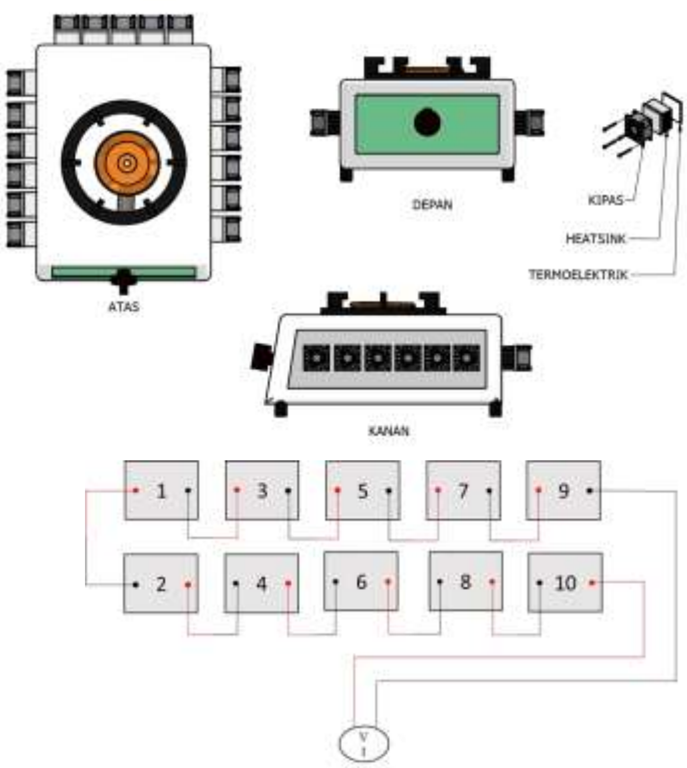


Figure 2. TEG Installation and Thermal Series Circuit

Figure 2 shows a single-stack thermoelectric generator module circuit. The cable connections are as follows: The red (+) cable of TEG 1 is connected to the black (-) cable of TEG 2, and the black (-) cable of TEG 1 is connected to the red (+) cable of the next TEG. For dual modules, the red (+) cable output is connected to the black (-) cable on the dual-stack thermoelectric module.

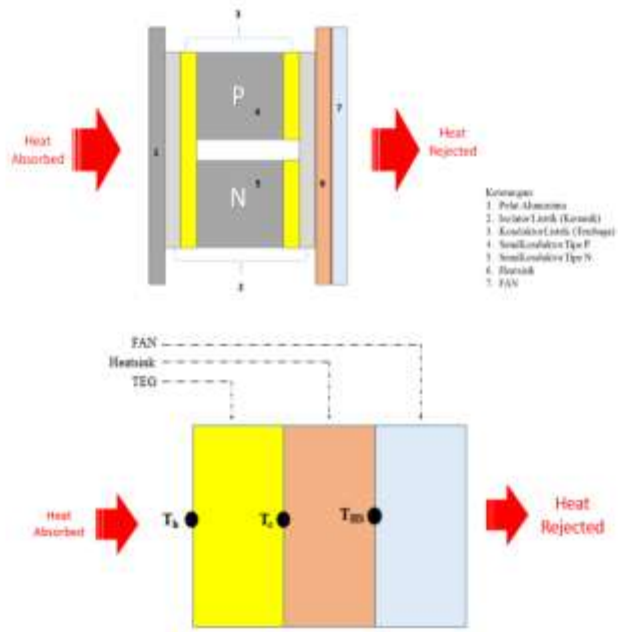


Figure 3. Schematic of measurement points on the test specimen

Figure 3 shows the measurement points on the test specimen, each of which is assigned three temperature measurement points: the hot side temperature on the TEG, the cold side temperature on the TEG, and the temperature on the heatsink.

f. Data Collection Method

In numerical theory, if a material to be observed is located between two identical symmetrical lines, a thermoelectric generator can be installed on one wall of a portable stove. This is because the matrix properties of the other material to be observed will be the same, affected only by the ambient temperature and flame temperature.

After installing the thermoelectric generator on the portable stove, experimental data collection was conducted using a variety of non-branded thermoelectric generator modules.

1. Before the portable stove was lit, all system components and measuring equipment were in good condition.
2. Measurements and data collection were conducted every 5 minutes after the combustion process began, including:
   a. Temperature measurement on the portable stove.
   b. Body (wall of the portable stove)
   c. Ambient temperature.
   d. Temperature of the hot side of the TEG
   e. Temperature of the cold side of the TEG
   f. Heatsink temperature
   g. Voltage generated by the TEG

3. RESULTS AND DISCUSSION

This section presents the results of performance testing of a thermoelectric generator (TEG) installed on a portable stove. The analysis was conducted to determine the system's ability to convert heat energy from combustion into electrical energy. The main parameters observed included the electric current generated, the amount of heat absorbed by the TEG module, the output electrical power, and the energy conversion efficiency. These four parameters are interrelated in describing the overall performance of the TEG system. The test data are presented in graphs and tables to facilitate analysis of the relationship between surface temperature differences and the achieved current, power, and efficiency.

Summary of Experimental Data

The experimental data obtained from the performance testing of the thermoelectric generator (TEG) installed on the portable stove are summarized in Table 3.1. These measurements include the hot-side temperature, cold-side temperature, temperature difference (ΔT), voltage, current, and electrical power recorded throughout the heating and cooling phases. The dataset reflects the dynamic thermal behavior of the stove–TEG system as the combustion intensity increases, reaches its peak, and gradually decreases. This table provides a complete overview of the electrical and thermal responses of the TEG module at each measurement interval, forming the basis for subsequent analysis of current generation, heat absorption, electrical power output, and conversion efficiency.

Tabel 1. Experimental Data (5-minute Interval Measurement)

Time (min)	Thot (°C)	Tcold (°C)	ΔT (°C)	Voltage (V)	Current (A)	Power (W)
0	31.50	30.40	1.10	0.10	0.002564	0.000256
5	34.20	32.10	2.10	0.20	0.005641	0.001128
10	37.20	33.80	3.40	0.33	0.009731	0.003211
15	40.10	35.60	4.50	0.64	0.017938	0.011409
20	43.70	37.50	6.20	0.74	0.019854	0.014742
25	48.00	39.80	8.20	0.89	0.023881	0.021182
30	53.70	43.70	10.00	0.99	0.026051	0.025764
35	57.50	45.60	11.90	1.39	0.036738	0.051065
40	61.60	47.40	14.20	1.54	0.039694	0.061089
45	66.40	49.80	16.60	1.81	0.046051	0.083121
50	71.00	51.20	19.80	1.93	0.049323	0.095292
55	74.50	53.10	21.40	1.99	0.05117	0.101675
60	78.20	54.80	23.40	2.01	0.05258	0.105896
65	73.50	51.10	22.40	1.88	0.050757	0.095423
70	66.80	45.80	21.00	1.44	0.040088	0.057727
75	59.80	41.20	18.60	1.13	0.031872	0.036015
80	52.90	37.10	15.80	0.83	0.02341	0.019431
85	44.30	33.70	10.60	0.45	0.012564	0.005654
90	37.50	29.70	7.80	0.15	0.004135	0.00062

Electric Current

The electric current graph in Figure 5 shows the relationship between heating time and the current generated by the Thermoelectric Generator (TEG) in a portable stove. At the beginning of the test, the electric current increased gradually as the temperature of the hot side rose due to the combustion process, while the cold side remained at its initial state, resulting in a larger temperature difference (ΔT). This increase in ΔT caused an increase in the electromotive force (EMF) through the Seebeck effect, thus increasing the current flow. The current reached a maximum value of approximately 0.0512–0.0526 A in approximately 55–60 seconds, indicating optimum conditions where the hot side temperature was at its highest and the cold side was still effectively cooled (the stove was on). After passing the peak, the electric current began to gradually decrease as the combustion intensity decreased and the temperature gradient between the two sides of the module decreased (the stove was turned off). This bell-shaped current change pattern indicates that the TEG's response to temperature changes is dynamic: it increases as the temperature difference increases and decreases as the heat source weakens. This maximum current value indicates that the TEG is capable of performing reasonably well for portable systems. These results align with research by Kim et al. (2020) and Jayanegara et al. (2020), which reported that an increase in temperature difference is directly proportional to an increase in output current, and a decrease in temperature causes the current to decrease significantly. Overall, this graph confirms that the stability of the electric current is highly dependent on heat management on the hot side and cooling on the cold side of the TEG module.

Figure 5. Electric current graph

Heat Absorption

The heat absorption graph, as shown in Figure 6, shows the relationship between heating time and the amount of heat energy absorbed by the Thermoelectric Generator (TEG) module during the combustion process on a portable stove. At the beginning of the test (0–20 seconds), the heat absorption was still low because the temperature of the stove wall and the TEG surface had not yet reached a stable state. Over time, the increase in the hot-side temperature and thermal transfer efficiency led to a significant increase in the absorbed heat energy. The highest heat value was reached at 55–60 seconds, with a value of approximately 30.78 Watt/m2, indicating that at that time, the maximum heat transfer between the stove metal surface and the TEG module occurred. After reaching the peak, the graph shows a gradual decrease until the end of the test, caused by reduced combustion intensity and natural cooling of the system, resulting in a decrease in the temperature difference between the hot and cold sides. This pattern forms a bell-shaped curve, illustrating that the module's ability to absorb heat is highly dependent on the stability of the heat source and the thermal conduction efficiency of the interface. These results align with research by Crane and Bell (2017) which states that increasing thermal contact between the heat source and the TEG can increase energy absorption by up to 25%, while imperfect contact or temperature fluctuations cause a decrease in absorption capacity. In general, this graph shows that the heat absorption process occurs optimally in the middle of the combustion time and is the main factor determining the amount of electrical energy that can be generated by the TEG system.

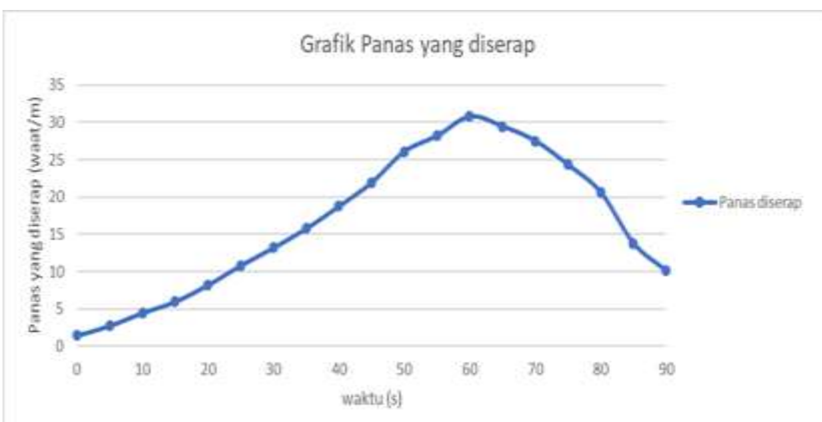


Figure 6. Graph of absorbed heat

Electrical Power

The electrical power graph (see Figure 7) shows a significant increase with increasing heating time, with a maximum value of approximately 0.102–0.105 W at 55 to 60 seconds. This increase occurs because the temperature difference (ΔT) between the hot and cold sides increases, resulting in higher Seebeck voltage and current. After the peak, the power decreases due to the decrease in the heat source temperature and reduced cooling effectiveness. This bell-shaped curve pattern indicates that the maximum power is reached at optimum thermal equilibrium conditions.

This phenomenon aligns with the findings of Ahamed et al. (2024), who explained that TEG power increases exponentially with ΔT up to an optimum limit before decreasing due to conductive heat losses. Furthermore, Wang et al. (2023) added that cold-side temperature control plays a critical role in maintaining power stability in waste-heat recovery systems, while emphasizing improved power factor ($S^2\sigma$) and reduced thermal conductivity (κ) as the keys to high efficiency.

Overall, this graph demonstrates that the performance of TEGs in portable stoves is highly dependent on thermal management. The maximum power rating of around 0.1 W demonstrates the system's potential as a portable micropower source, with potential for improvement through cooling optimization and the selection of high-ZT materials.

Figure 7. Electrical power graph

Efficiency

The efficiency graph (see Figure 8) shows that the Thermoelectric Generator (TEG)'s ability to convert heat energy to electricity increases over time, peaking at around 0.37% at 45 seconds, then gradually decreases. The initial increase in efficiency occurs because the temperature difference (ΔT) between the hot and cold sides increases, resulting in greater Seebeck voltage and electrical power. After reaching optimum conditions, efficiency decreases due to reduced combustion intensity, increased heat losses, and decreased cooling stability.

This pattern indicates that maximum efficiency is only achieved at ideal thermal equilibrium. According to Zebarjadi et al. (2021), TEG efficiency at low temperatures is generally below 5% due to limitations in the figure of merit (ZT) and heat losses at the interface (Micromachines, 12(7):734). Meanwhile, Nowak et al. (2023) emphasized that efficiency decreases again when the ΔT is too high without optimal cooling, because some heat energy is lost before conversion.

Overall, the peak efficiency of around 0.4% in the portable stove system is still considered reasonable for a non-branded TEG module and can be improved through thermal contact optimization and the use of materials with higher ZT values.

Figure 8. Efficiency graph

4. CONCLUSION

Based on the results of testing and analysis of the performance of a thermoelectric generator (TEG) applied to a portable stove, it can be concluded that the temperature difference between the hot and cold sides significantly affects the current, power, and energy conversion efficiency produced. The maximum current reached approximately 0.0526 A, with a peak output power of 0.105 W and a maximum efficiency of approximately 0.37%. Optimal performance is achieved when the temperature gradient is at a thermal equilibrium point, where the hot side receives maximum heat supply and the cold side is effectively cooled. Although the conversion efficiency is still relatively low, this system shows potential as a portable micro-power generator that can be utilized in areas without electricity access or as a supplemental power source for small devices. Improved TEG performance can be achieved through thermal contact optimization, more efficient cooling design, and the use of materials with a higher figure of merit (ZT). This research provides a foundation for further development of waste heat-based thermoelectric technology as an environmentally friendly alternative energy solution and supports the implementation of renewable energy in the future. Future work should consider several improvements to enhance the performance and practicality of TEG-based portable power systems. The use of commercial high-ZT modules is recommended to increase conversion efficiency beyond the limitations of the low-cost modules used in this study. Additionally, implementing more advanced cooling designs—such as optimized airflow configurations, larger heatsinks, or enhanced thermal dissipation mechanisms—would help maintain a greater temperature difference across the module and improve overall performance. Testing the system with real electrical loads is also essential to evaluate its practical capability in powering actual devices rather than relying solely on open-circuit output measurements. Furthermore, thermal modeling is suggested to better understand heat distribution within the stove–TEG interface and to optimize heat routing for maximum energy conversion. Overall, this research provides a fundamental basis for the development of low-cost TEG systems that support portable renewable energy applications in off-grid environments.

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