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Electrical Power Generation from Refrigerator Waste Heat Using Thermoelectric Generator for Small Device Charging

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Abstract

This project aims to explore the potential of recovering waste heat from domestic appliances, specifically refrigerator condenser coils, to generate electrical power for low-power applications. Energy harvesting is achieved by utilizing the Seebeck effect through six thermoelectric modules (TEC1-12706) connected in series to maximize the total voltage output. The methodology involves the construction of a thermal sandwich structure consisting of an aluminum heat spreader plate, the Peltier modules and a finned heat sink equipped with an active cooling system (DC fan). A primary challenge in thermal transfer bridging the gap between the curved surface of the condenser coils and the flat surface of the modules was addressed through the application of high-conductivity thermal grease and a robust mechanical clamping system to minimize thermal resistance. The harvested electrical energy is processed via a DC-DC boost converter (XL6009) to stabilize the output at 5V, which is then used to charge 18650 Lithium-ion cells through a USB power bank module. Preliminary results indicate that the system is capable of generating sufficient voltage to charge mobile devices sustainably, relying solely on the temperature gradient between the refrigerator's waste heat and the ambient air. This project demonstrates the feasibility of green energy harvesting concepts in improving energy efficiency within a residential environment.

1. Introduction

In the 21st century, using energy resources efficiently is a big challenge. Even with advances in power generation, about 60% of energy used worldwide is wasted as heat released into the environment [1]. Recovering this lost energy, called Waste Heat Recovery (WHR), is important for making systems more efficient, reducing carbon emissions, and meeting climate goals. This has led to research on new ways to turn heat into electricity, especially from small, low-temperature sources that big heat engines usually ignore [2].

One promising technology for capturing low-grade heat is the Thermoelectric Generator (TEG). TEGs are devices that convert temperature differences into electricity using the Seebeck effect. They are quiet, have no moving parts, are reliable, and can be scaled up or down, making them good for use in consumer devices where maintenance and noise are issues. Although TEGs have been less efficient than traditional methods, new materials, especially from nanotechnology, are improving their ability to convert heat into electricity, making them more useful for many WHR applications [3].

Household refrigerators are a common source of wasted low-grade heat. They constantly release heat through the condenser coil, which is usually warmer than the surrounding air. This study looks at using a TEG system to capture this waste heat from refrigerators. The electricity generated, though small, can help power small electronic devices like smartphones and sensors. By improving the TEG-refrigerator connection, this study aims to show how to turn a common source of heat waste into clean energy, improving refrigerator energy use and supporting small-scale energy generation [4], [5].

Energy harvesting, also known as energy scavenging, is the process of capturing energy from the environment, like light, heat, vibrations, or radio waves, and turning it into electricity. Unlike using batteries to store power, energy harvesting focuses on constantly generating power from the surroundings. This technology is important for Wireless Sensor Networks (WSNs), Internet of Things (IoT) devices, and low-power portable electronics because it reduces or removes the need to change batteries often. The aim is to create systems that power themselves and work continuously by using energy available nearby [6].

Recent improvements in TEG technology focus on two main areas: better heat management and more power output. First, good heat transfer in TEGs is very important, especially for low-temperature sources. Researchers have looked into using special fluids between the heat source and TEG to reduce contact resistance and make heat flow more evenly. Studies, like those by Zhao et al. (2024), show how these fluids help heat move into TEG modules better [7]. This is important for refrigerators where the condenser surface might not be even. Second, TEGs are getting better in terms of integration and power density. Although this study looks at a stationary use, new materials have led to wearable TEGs that are small, efficient, and can provide enough power for charging [8]. This shows that TEGs can be extra power sources for small devices, supporting the main idea of this thesis.

1.1 Problem Statement

Despite efforts to make home appliances more energy-efficient, refrigerators still release a lot of heat into the air. This heat loss means energy is wasted, making homes less efficient. While Waste Heat Recovery (WHR) is a good idea, current WHR technologies are often too big or expensive to capture the small temperature difference from home fridges, which is usually 10 to 30 degrees above room temperature. The main challenge is turning this small, steady heat difference into useful electricity. Also, with many small electronic devices in homes, there is a need for easy and sustainable power sources. Therefore, there is a need for a solid-state solution that can use the fridge's waste heat to produce enough electricity to charge small electronics. This research aims to fill this gap by creating and testing a Thermoelectric Generator (TEG) system that can use this common waste heat source effectively and sustainably.

1.2 Objective

The objectives of this project are to develop a sustainable energy harvesting system utilizing the waste heat generated by domestic refrigeration cycles. To achieve this, the project first aims to investigate the potential thermal energy available from refrigerator compressor and condenser coils to determine the feasibility of energy conversion. Subsequently, the study focuses on the design and development of a 10-unit Thermoelectric Generator (TEG) array integrated with an XL6009 boost converter, specifically engineered for small device charging applications. Finally, the project seeks to examine the performance and effectiveness of the prototype by analyzing the temperature gradient maintenance and the consistency of the electrical output under real world operating conditions.

1.3 Project Scope

This study focused exclusively on a single commercially available domestic vapour compression refrigerator. The sole source of thermal energy utilized for harvesting is the waste heat rejected by the condenser coil. The TEG assembly will utilize commercially available pre-fabricated thermal semiconductor modules, and the research will not involve the optimization, synthesis, or physical alteration of the semiconductor material itself. The primary objective of electrical generation is to produce a small, stable auxiliary power source. The system design includes a necessary power conditioning circuit (DC-DC conversion) to regulate the raw TEG output to a stable 5V DC supply. This output is specifically intended for charging low-power portable electronic devices, such as smartphones and smartwatches, through a standard USB interface.

2. Materials and Methods

2.1 Main Components

The prototype for this project are shown in Fig. 1. The main component for this project is thermoelectric generator (TEG). A thermoelectric generator (TEG) is a device that changes heat into electricity using the Seebeck effect. This effect happens when there is a temperature difference between two different conductors or within a conductor circuit, creating an electric potential difference [9]. TEGs are solid-state devices, which means they have no moving parts. This makes them quiet and reliable for long periods. They can capture waste heat from places like factories, cars, power plants, and even body heat, turning it into electricity. TEGs can also power remote devices like sensors, wireless transmitters, and spacecraft by using radioisotopes or solar heat as the heat source [9].

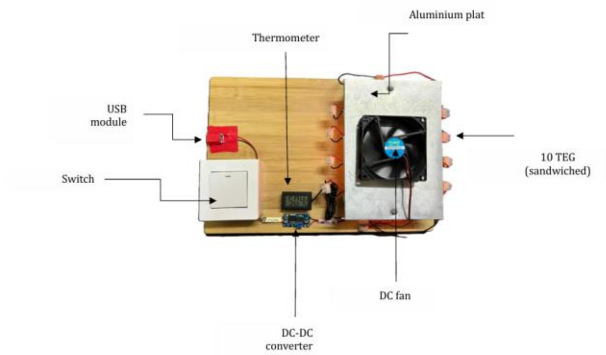

Fig. 1 *Prototype of this project*

Fig. 2 illustrates the flow of the project where heat source is coming from back of the refrigerator (compressor). When the interaction of heat with TEG happen, it will produce electricity and voltage. It can be use to charge a small device.

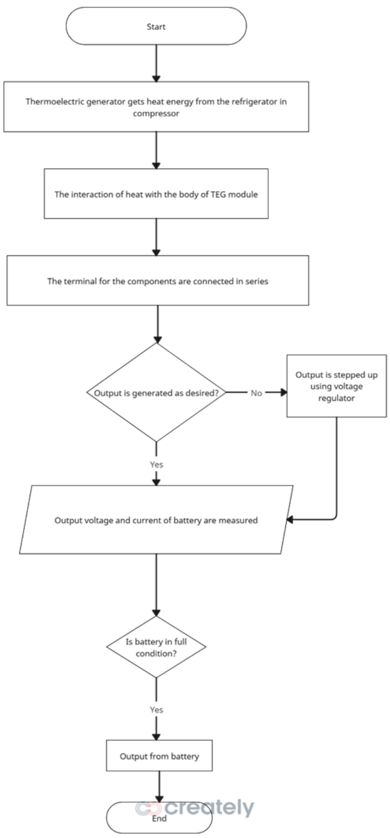

Fig. 2 *Flowchart of the project*

Fig. 3 illustrates the sequential flow of energy conversion and power conditioning within the prototype. The system operates through a four-stage process to transform thermal energy into a stabilized electrical output. The process begins with the application of heat to the hot side of the Thermoelectric Generator (TEG) array. The stabilized power is delivered to the load, which can be a small device charging or power bank module for energy storage.

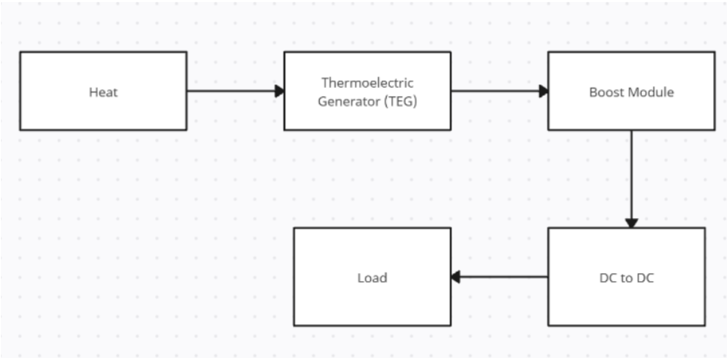

Fig. 3 *Block diagram of the project*

3. Results and Discussion

This section will discussed the result of the project. Fig. 4 shows the prototype being placed at the back of refrigerator. The hot side (bottom) aluminum plate of the TEG sandwich is placed directly against the refrigerator's surface. To minimize thermal contact resistance and maximize heat flux, a thin layer of thermal conductive grease applied between the refrigerator wall and the aluminum plate. The vertical placement allows natural convection to assist the active cooling system. It also ensures the device does not interfere with the refrigerator's internal cooling cycle or airflow. The unit is placed near the condenser assembly where surface temperatures typically range from 40°C to 60°C, providing the necessary thermal input for the Seebeck effect to occur.

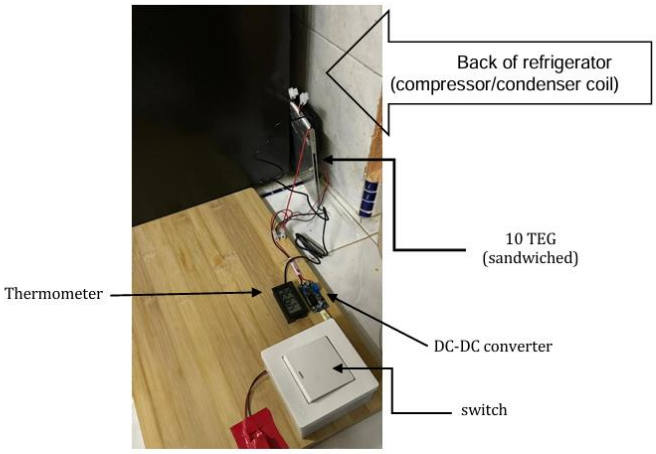

Fig. 4 *Prototype placement*

A single TEC1-12706 module was tested to see how much voltage it can produce when heated. Fig. 5 shows that heat was applied to one side of the module. The test showed that one thermoelectric generator (TEG) can produce up to 1.35V. This is important because it proves the Seebeck Effect, which turns heat differences into electricity. If you connect several TEG modules in a row, the voltage adds up. With ten modules, the system can make about 10V to 13V, depending on the heat from the refrigerator. For charging small devices, at least 5V is needed to power the XL6009 DC-DC Boost Converter and the USB charging module. The 1.35V from one module shows that using several modules together will easily meet the voltage needed to start the power circuit, making energy collection reliable.

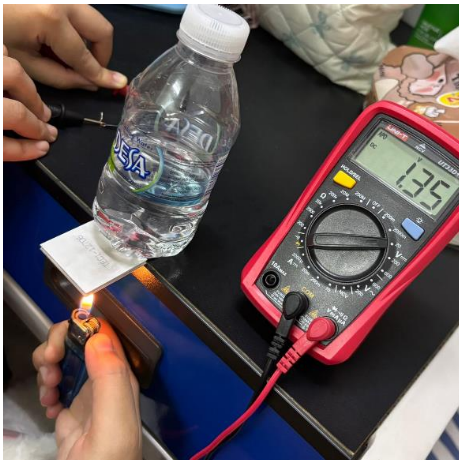

Fig. 5 *TEG testing*

Table 1. shows the time taken for the phone to be charged. The data shows the phone is being charged from 20% up to 100% which indicates full.

Table 3.3

Time taken (hours)	Percentage of the battery
1-2	20%
2-3	31%
3-4	45%
4-5	62%
5-6	79%
6-7	87%
7-8	96%

The series configuration demonstrated superior voltage generation, achieving a peak of 0.40 V, significantly higher than the 0.142 V in the parallel setup. This makes it more suitable for devices requiring stable and higher voltages. The cumulative voltage from the series connection is particularly advantageous for powering sensors and control systems. The series connection leverages the TEGs' sequential arrangement to maximize voltage output, which is critical for applications where voltage stability is a priority. This higher voltage output demonstrates the configuration's efficiency in maximizing electrical potential through thermal energy harvesting.

Parallel configurations significantly outperformed series setups in current generation, reaching a peak of 0.33 A compared to 0.14 A. The parallel setup ensures lower resistance pathways, enabling efficient current flow. This characteristic makes it ideal for applications where power distribution across multiple devices is necessary. The higher current output from parallel configurations emphasizes their practical value in dynamic systems that demand substantial and consistent current levels for optimal operation.

The integration of thermal paste and heat sinks proved pivotal for both configurations. By reducing thermal resistance and enhancing heat dissipation, these components ensured stable temperature gradients and optimized energy conversion. The results showed significant improvements in power output for both series and parallel setups, demonstrating the importance of effective thermal management. The enhancements provided by these components underscore their role in achieving efficient thermoelectric energy harvesting and ensuring reliable long-term system performance. Fig. 6 shows the comparison graph showing the peak voltage and current generation for series and parallel configurations. The blue bars represent voltage, while the green bars represent current. As shown in Fig. 6, the series configuration produces higher voltage, while the parallel configuration generates more current. This highlights the strengths of each configuration for different types of applications.

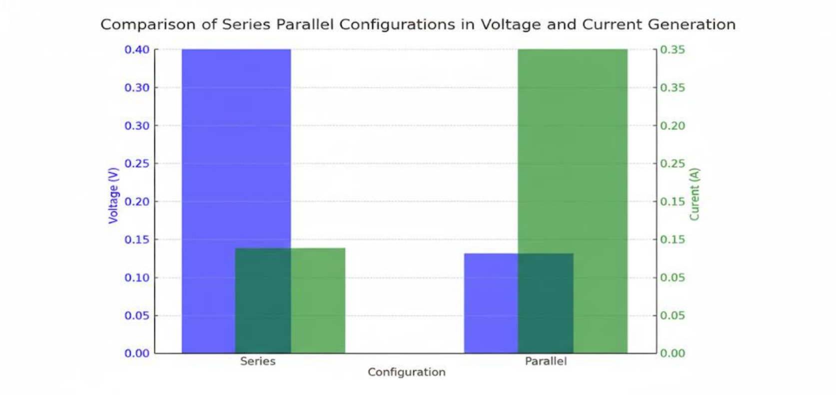

Fig. 6 *Comparison of series parallel configuration*

4. Conclusion

The project to create a self-sustaining system that uses waste heat from refrigerator coils is complete. It uses a ten-unit TEC1-12706 array and an XL6009 DC-DC boost converter to turn low-level heat into electrical power. A self-cooling loop, powered by the harvested energy, keeps the system from overheating and maintains a stable temperature. The XL6009 converter effectively increases low voltages (1.5V - 3V) to a stable 5V DC output. Although the system without a battery struggles to provide the high current needed for modern smartphones, it works well for low-power electronics. To improve this system, future researchers should consider adding an 18650 Li-ion battery or a Supercapacitor bank. This would store energy when the refrigerator's compressor is on and provide bursts of power for charging smartphones. Using high-performance graphene-based thermal pads instead of standard thermal paste could improve heat transfer, making the system more efficient. A low-power MPPT controller could help get the most power from the TEG array as the refrigerator's temperature changes, ensuring the XL6009 works efficiently. Future designs might use flexible TEG modules that wrap around the condenser coils to capture heat better than flat plates.

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References

[1] Aridi, R.; Faraj, J.; Ali, S.; Lemenand, T.; Khaled, M. Thermoelectric Power Generators: State-of-the-Art, Heat Recovery Method, and Challenges. Electricity 2021, 2, 359–386. https://doi.org/10.3390/electricity2030022

[2] Clean Energy Breakthrough Turns Waste Heat Into Usable Electricity. (2024, November 29). SciTechDaily. https://scitechdaily.com/clean-energy-breakthrough-turns-waste-heat-into-usable-electricity/

[3] Punith. N, Swamy, G. M., & Shivasharana Yalagi. (2018). A Thermoelectric Generator Systems Forwaste Heat Recovery- A Review. International Journal of Engineering Research & Technology, 3(17). https://doi.org/10.17577/IJERTCONV3IS17021

[4] Mishra, P., Pramod, C., & Mishra, K. (2025). Two-Days National Conference on Multidisciplinary Approaches for Innovation and Sustainability: Global solution for contemporary Challenges- NCMIS (DPG Degree College: 17 th -18 th 2025) Recovery of waste heat from domestic refrigerator. ~ 96 ~ International Journal of Research in Engineering, 2, 96–99. https://doi.org/10.33545/26648776.2025.v7.i2b.98

[5] M, G. (2024, November 22). Heat to Energy Conversion: Turning Heat into Power In 2025. Consumer Energy Center. https://www.consumerenergycenter.org/heat-to-energy-conversion/

[6] What is Energy Harvesting? What is Energy Harvesting Challenges？ - Orbray MAGAZINE - Orbray Co., Ltd. (n.d.). https://orbray.com/magazine_en/archives/437

[8] Zhao, Y., Zhang, G., Wen, L., Wang, S., Wang, Y., Li, Y., & Ge, M. (2024). Experimental study on thermoelectric characteristics of intermediate fluid thermoelectric generator. Applied Energy, 365, 123263–123263. https://doi.org/10.1016/j.apenergy.2024.123263

[9] Miao, L., Zhu, S., Liu, C., Gao, J., Zhang, Z., Peng, Y., Chen, J.-L., Gao, Y., Liang, J., & Mori, T. (2024). Comfortable wearable thermoelectric generator with high output power. Nature Communications, 15(1). https://doi.org/10.1038/s41467-024-52841-1

[10] Thermoelectric Power Generators or Seebeck Power Generation | Electrical4U. (n.d.). Https://Www.electrical4u.com/.https://www.electrical4u.com/thermoelectric-power-generators-or-seebeck-power-generation/